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SOVIET INSTRUMENTATION AND
CONTROL TRANSLATION SERIES

# Measurement Techniques

(The Soviet Journal *Izmeritel'naya Tekhnika* in English Translation)

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# SOVIET INSTRUMENTATION AND CONTROL TRANSLATION SERIES




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# Measurement Techniques

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Russian Original Dated April, 1961

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## CONTENTS

# SOME RESULTS OF THE WORK OF METROLOGICAL INSTITUTES IN 1960

L. M. Zaks

Translated from Izmeritel'naya Tekhnika, No. 4,
pp. 1-4, April, 1961

The high level of measurement techniques is one of the most important conditions for the development of modern science and for technological progress in all branches of the USSR national economy. The more rapid this development, the more exacting become the requirements which measurement equipment must attain with respect to accur- and sensitivity of measurements, the extension of its range to extremely large and small values, and precision measurements of rapidly changing processes.

The considerable successes of our sciences and technology in recent years have sharply raised the requirements which measurement equipment has to meet. Especially exacting requirements for raising the accuracy and extending the range of measurements arise in the rapidly developing new technologies, such as radioelectronics, atomic energy, rocketry, cosmic navigation, computers, as well as the entire sphere of automatic monitoring and control of industrial and other processes.

In many instances accuracy requirements for commercial measurements attain those of reference measurements. Under modern conditions metrology should in fact embrace all the precision measurement techniques in the country, since the peculiarities and methods of reference measurements are being increasingly extended to practical precision measurements in scientific research, industry and agriculture.

The rapid development of metrology and precision measurement technique in advance of requirements is necessary both for the immediate development of all branches of scientific research and in order to satisfy the practical requirements of various industries, such as precision engineering, precision control of the most varied special production processes, as well as for the calibration, testing and checking of all the measuring equipment in our country. The possibility of developing and organizing the production of any measuring equipment by the existence of appropriate methods and high-precision reference instruments for calibration and testing.

Therefore, the development of metrology and precision-measurement techniques and new measuring methods which provide the required accuracy over wide measuring ranges, and production of high-precision measuring equipment are the most important and decisive conditions for the development of the measurement techniques and of instrument-making as a whole, a prerequisite for the development of scientific research and the acceleration of technical progress in our country.

The activity of the metrological institutes of the Committee of Standards, Measures and Measuring Instruments was aimed in 1960 at fulfilling the tasks set by the June (1959) and July (1960) Plenary Sessions of the CPSU (Communist Party of the Soviet Union) Central Committee on the acceleration of technical progress in the USSR.

The main trends in the activity of the institutes consisted of:

1. Scientific research and experimental design work for improving and establishing new standards, reference methods and equipment in all branches of measurements. The development of new precision-measuring methods, of reference equipment and methods for calibrating, checking and testing instruments, of methods for testing the most important physical and chemical properties of materials. Work in determining certain important physical constants. Attending to the state time and frequency service. Investigating the methods and evaluating measurement errors and deriving tolerances for measuring instruments. Compiling specifications, such as metrological standards, instructions and operating directions for checking instruments. Participating in the work of international metrological and standardization organizations. Preparing information material such as collections of works, monographs and reviews in various spheres of metrology and precision-measurement techniques.

2. Organizing and carrying out state testing of newly developed measures and measuring instruments which are being put into mass production.

3. Organization of state inspection by the Committee's agencies in their respective regions of instrument production, the state and application of measurement equipment in industry, agriculture, trade and transport. Controlling and rendering assistance in organizing service inspection of the measurement equipment in plates, rendering assistance and guiding the work of State Inspection Laboratories of other regions assigned to the Committee's institutes.

The most important results of the work so far completed in the sphere of linear and angular measurements include, in the first place, the change-over to the new definition of the meter by means of the krypton-86 orange line adopted by the 11th General Conference on Weights and Measures in October, 1960. In addition to producing a new design for the krypton lamp the VNIIM (All-Union Scientific Research Institute of Metrology) has achieved important results in establishing secondary standards, by obtaining narrow spectral lines by means of partial absorption. Cadmium isotopes have been determined between which it is possible to obtain an "atomic" slot for the cadmium triple line; a method has been found for narrowing the mercury green line by means of a thermal iodine filter. The universal interference comparator has been improved with the object of direct measurements of linear standards in monochromatic light. The development of a technique and means for measuring the linearity of large objects up to 50 m long is of great practical importance. Measurements made on lengths up to 30m long have shown that the quadratic mean error does not exceed 5 $\mu$/m.

Tests of the radiointerferometer in the millimeter range developed by the KhGIMIP (Khar'kov State Institute of Measures and Measuring Instruments) have shown that the measurements of the propagation of electromagnetic waves by means of this instrument can be made with an error not exceeding a few units of the seventh order. Further work in this connection is planned for 1961. The same institute has developed a pneumatic method for checking block gauges, which greatly increases labor productivity in testing.

The VNIIK (All-Union Scientific Research Institute of the Committee of Standards, Measures and Measuring Instruments) has developed a horizontal interferometer angle-measuring set for certifying polyhedral grade I prisms in the range of 10 to 100° with an error not exceeding 0.2-0.7", and an autocolimation set based on goniometer GS-5 with an error of 1". An equipment for measuring the radii of concave reference glass spheres in the range of 87.5-1000 mm with an error of 0.01% of the measured radius should also be mentioned.

In the sphere of mechanical measurements mention should be made of the compact reference weighted-piston grade 1 manometer developed by the VNIIK, measuring up to 2.5 kg-wt/cm$^2$ with an error not exceeding 0.02%. This instrument will be widely applied in substitution for mercury manometers and the cumbersome and less accurate weighted-piston manometers previously developed by the VNIIK.

Great importance should be attached to the research carried out by the VNIIFTRI (All-Union Research Institute for Physicotechnical and Radiotechnical Measurements) on methods for raising the upper limit of reference instruments for measuring ultrahigh pressures exceeding 25,000 kg-wt/cm$^2$, and also to its work in measuring physical properties of matter (viscosity, density) at pressures up to 10,000 kg-wt/cm$^2$.

For accurate measurements of very small pressures the VNIIM has produced a reference micromanometer measuring from 0.2 to 10 kg-wt/m$^2$, with an error of 0.01 kg-wt/m$^2$.

Special attention should be paid to the successful work being carried out by the VNIIM in precision measurements of velocities, accelerations and vibrations. In 1960, the VNIIM produced and certified experimental models of the previously developed tachometer equipment measuring up to 60,000 rpm with an error of 0.01%, and is at present working on the extension of this range up to 150,000 rpm. An equipment for producing and measuring pulse accelerations of 1 to 10 g has been developed, produced and tested. A reference vibrometric equipment has been produced for frequencies up to 2000 cps and accelerations up to 150 g. This work has prepared a good metrological foundation for certifying the measuring equipment used in testing mechanical reliability.

The Sverdlovsk branch of the VNIIM has produced experimental models of portable reference dynamometers for measuring moments (momentometers) from 100 to 2000 kg-wt·cm with an error not exceeding 0.5%, thus making it possible to check torsion testing machines.

It is interesting to note the work conducted by the VNIIM in producing an automatic equipment with two calibrated tanks for continuous measuring of gas, and by the KhGIMIP in making a reference flowmeter based on the use of the Coriolis force for an efficient testing of watermeters with an error not exceeding 0.5-0.7%.

In 1960 work on temperature and heat measurements, was further developed in the Committee's institutes. Important calibrations of the gas thermometer were made at the VNIIM, which led to the determination of an additional reference point, that of the solidification point of cadmium (321.03°C). The accuracy in measuring the triple point of water has been raised by almost one order (up to ±0.0002°C). Considerable work was carried out in developing the theory, technique and apparatus for measuring rapidly changing temperatures and for determining the error of measurement of the equipment used for the purpose. The development was completed of a new productive differential equipment for checking highly accurate radiation pyrometers, and of an oven checking precious-metal thermocouples up to 1800°C.

The Sverdlovsk branch of the VNIIM developed the technique and equipment for determining the characteristics of thermal electrode materials at temperatures up to 2000°C.

The KhGIMIP designed a compact reference "blackbody" radiator with a range up to 3000°C which consumes small power and can be used for checking pyrometers, and it continued its work on producing reference sources for higher brightness temperatures, and its research on a radiopyrometer. The VNIIM and KhGIMIP continued their investigation of methods for measuring ultrahigh temperatures. The VNIIM investigation of new absolute methods for measuring low temperatures, namely of the electroacoustical and thermal noise methods, were further developed.

The VNIIFTRI continued its work in establishing a temperature scale between 4 and 10°K, and completed the design of a reference dilatometer of a simple construction with a measurement error amounting to $1\cdot10^{-7}$, i. e., of the order of the interferometer method. On this basis work is continuing in producing models for certifying dilatometers.

For determining the thermal characteristics of materials the VNIIM has developed an equipment for measuring the thermal conductivity of semiconductors, and the thermal and temperature conductivity of plastics over wide ranges of low and high temperatures. The Sverdlovsk branch of the VNIIM has developed an equipment for high-precision calorimetric measurements up to 1500°C.

In the sphere of optical and photometric measurements the VNIIM has improved the light standard which has a dispersion not exceeding 0.5%. It has also developed a new apparatus for checking dioptric meters for lenses of a complex shape (for ophthalmic optics). The institute also produced a comparator equipment for color measurements with an objective readout which makes it possible to differentiate between samples with small color differences, and produced a series of reference luminescent light-intensity measuring lamps, which produce luminous fluxes of 600 to 2500 lu of different colors. The VNIIK has also developed and produced a set of reference prisms for checking refractometers with refractive indexes of 1.3 to 1.8 and an error of $5\cdot10^{-6}$.

The metrological work of the VNIIM and its Sverdlovsk branch was carried on successfully in 1960 in the sphere of physicochemical measurements. Test sets for checking pH-meters and gas analyzers was developed, an equipment for obtaining reference gas mixtures was produced. A technique and apparatus was developed for checking commercial gas analyzers of nitrogen oxide, sulphur oxide, oxygen and other gases. Methods for certifying reference buffer solutions were devised and the solutions prepared, whose pH values were established with an error of 0.01. Isotope methods for analyzing certain substances were developed.

In the sphere of electrical and magnetic measurements the VNIIM carried out fundamental research in determining the gyromagnetic ratio for protons, obtaining for it the value of 26,750.5 oe/sec with a quadratic mean error of ± 0.05. Portable grade 2 standard dry cells were developed for portable measuring equipment. A large amount of work was completed on developing precision measuring methods of electrical circuit parameters over a wide frequency range. Among other things, the Institute produced a set of reference capacitances which consists of coaxial and cylindrical three-terminal capacitors with values up to $400\mu\mu f$ for frequencies up to 100 Mc. The Sverdlovsk branch of the VNIIM developed a technique and produced equipment for determining the pulsed magnetization curve of magnetic materials for pulse durations of 0.1 to 20 $\mu$ sec, and a repetition frequency of 50 to 5000 cps, with an error of 5-7%. The NGIMIP (Novosibirsk State Institute of Measures and Measuring Instruments) developed an apparatus for dc testing of small samples (mean radius of 0.5 mm) of magnetically soft materials. It also developed a set of high-frequency permeameters for determining the magnetic characteristics of carbonyl iron.

The most important work in the sphere of radiotechnical measurements during 1960 was carried out in connection with completing the development of a standardized set of reference instruments for the radiometric test and inspection laboratories organized by the Committee's institutes in 1961. This standardized set developed in cooperation between all the institutes on the basis of the scientific research and experimental design work carried out both

by the Committee's agencies and by industrial institutes, comprises reference instruments required for high-precision measurements of voltages, currents, powers, attenuations, reflection factors, noise and pulse characteristics for all the frequencies used in practice in high and ultrahigh ranges. This equipment can also be used for checking the corresponding radio-measuring instruments.

Provisions were made for the newly organized test and inspection laboratories of the Institutes to serve as centers for state and routine testing of the newly developed and produced radio-measuring instruments, and to certify reference equipment used in industrial service laboratories as standards for checking commercial instruments.

In 1960 work was carried out for the improvement of the time and frequency service carried of the Committee's Institutes. A round-the-clock transmission of standard frequencies and the time signals from two Moscow radio stations has been organized. These transmissions are based on standard crystal and molecular oscillators with a daily instability not exceeding $1 \cdot 10^{-9}$. The time and frequency service is being supplied with new atomic frequency standards which, in conjunction with improved crystal resonators will provide a further improvement in accuracy.

In the sphere of ionizing radiation measurements the VNIIM modernized a number of installations for dosimetric and x-ray measurements, developed a reference dosage meter measuring $100\mu$r/sec to 1r/sec in quanta energy range of 20 to 1000 kev, and developed the technique and equipment for measuring external radiations of distributed alpha and beta sources. The work of test and inspection laboratories for ionizing radiations is being organized at the VNIIM and NGIMIP.

In 1960, considerable efforts were exerted to make the model gauges and instruments developed by the institutes generally available, by producing experimetal batches at the "Étalon" plant attached to the VNIIM, by making them at the VNIIFTRI and the experimental production workshops of other institutes, as well as by starting their mass production at the Sovnarkhoz plants.

The production of a number of installations, gauges and instruments developed by the institutes was started in 1960, including a reference tachometric equipment measuring up to 60,000 rpm with an error of 0.01%, a reference thermistor UHF power meter, reference equipment for measuring low temperatures, equipment for checking optical and radiation pyrometers, a 100-ton weight-checking railroad car, a reference installation for checking large inductances and capacitances, several portable test sets, etc.

However, the ever-increasing requirements of scientific research establishments, of plants and state inspection laboratories for reference equipment used in precision measurements and in checking commercial instruments, considerably exceed the very limited production capacity of the institutes' experimental workshops, which are mainly engaged in experimental work on newly developed apparatus. We should insist on a radical change in the attitude of the planning authorities and Sovnarkhozes to the production of reference equipment at the instrument-making plants, in view of the fact that the availability of this equipment is a most important condition for ensuring high-quality production of all instruments and for maintaining their efficiency under working conditions, not to mention the requirements of scientific institutions in precision measuring equipment for their research work.

In addition to their scientific research the institutes also extended their work in carrying out state tests of the new instruments being developed by our industry. On the basis of the new regulation 2-59 of the Committee, introduced at the beginning of 1960, state tests of gauges and measuring instruments were carried out by the institutes with the wide participation of interested organizations, including various state committees, ministries, industrial research organizations, plants and state inspection laboratories. Some 400 models of new gauges and measuring instruments were tested under such conditions.

At the Committee's session on February 21-23, 1961, the directors reported on the work carried by their institutes in 1960. The Committee noted certain achievements in the work of the institutes, and at the same time severly criticized a number of failings in their work. Among other things, it noted the necessity for reducing the time taken by some of the research work, for an intensified supervision that the new equipment is adopted in industry. It also noted the lagging of the VNIIM mass and force measuring laboratories, the necessity to intensify the work in the sphere of physicochemical analysis and ionizing radiation measurements. It proposed the acceleration of the compiling of specifications and operating instructions for checking various new types of instruments, and speeding up the issuing of handbooks on precision-measurement techniques. The Committee noted the necessity for a further improvement in the system of state testing of guages and measuring instruments with a wider participation of the interested administrations, Sovnarkhozes and area industrial organizations in preparing and carrying out these tests, and for a further raising of the part played by the state inspection laboratories in this testing, and a stricter supervision of instruments both in general and specialized use.

The Committee outlined as the main tasks of the institutes an accelerated development of metrology and the technology of precision measurements in order to satisfy the most urgent requirements of science and of the most important branches of our national economy, as well as the stimulation of technical progress in instrument-making. The pledges made by the institutes to the forthcoming 22nd Congress of the CPSU duly reflect these tasks.

# LINEAR MEASUREMENTS

## GOMZ (STATE OPTICO-MECHANICAL PLANT) INSTRUMENTS FOR LINEAR AND ANGLE MEASUREMENTS*

N. F. Delyunov and É. I. Rozenberg

Translated from Izmeritel'naya Tekhnika, No. 4,
pp. 5-9

The state optico-mechanical plant is one of the leading factories in the Soviet Union in producing precision instruments for linear and angle measurements. The factory mass produces over 30 such instruments with auxiliary devices and a large number of experimental and specially ordered instruments.

Universal measuring microscopes. For more than 14 years the plant has been manufacturing a universal measuring microscope type UIM-21 for measuring in rectangular and polar coordinates linear and angular dimensions of various articles. This instrument is widely used both in industry and in research institutes.

The UIM-21 instrument is supplied with a large number of attachments, which extend the sphere of its application and raise its universality. These devices include: a table ST-2 with high centers for measuring threads of various articles with diameters between 90 and 250 mm; a round table ST-9 for measuring angles of various articles fixed in centers; attachment IZO-1 for internal linear measurements by a contact method; a double-image eyepiece head OGU-22 for measuring distances between hole centers up to 13 mm in diameter; knife bearings type OP-23 for measuring long and centerless articles; attachment PN-7 for projecting an amplified image of the article on a screen; an optical vertical distance gauge IZV-21 for measuring the external third coordinate, height of article [1]; a profile head OGR-23 for measuring metric threads and radii of various arcs; exchangeable objectives MT-22, MT-23 and MT-24 with magnifications of 5, 1.5 and 1; engraving knives and other attachments.

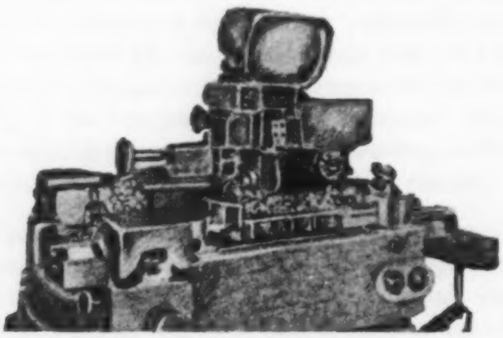

Fig. 1. Universal measuring microscope type UIM-23.

The design of the UIM-21 microscope has to a great extent become obsolete from the point of view of its operational facilities and ease of handling. For this reason a new universal measuring microscope, trade mark UIM-23 (Fig. 1) was developed. It is intended to replace instrument UIM-21. Mass production of UIM-23 should begin in 1961.

*From the papers read in 1960 at the Leningrad conference on optical methods for measuring lengths and angles and at the conference on measurement techniques of the Estonian Republican Council of scientific and technical societies (Tallin). Several of the instruments described in the article are experimental and have not yet passed their state test.

The sighting system of UIM-23 has been changed as compared with UIM-21. Instead of the main microscope an optical system is used which projects the image of the measured article onto a screen. When working with reflected light the projector may be replaced by a binocular attachment. The two readout microscopes with eyepiece screw micrometers have been replaced by a projection readout system. The scales of the longitudinal and transverse readout systems are projected onto a single screen conveniently placed before the operator. The new design makes it possible for the operator to work in a convenient sitting position, and the instrument is mounted on a special support which forms part of its equipment.

It is possible to use with the UIM-23 instrument all the attachments of the UIM-21 instrument, which are mounted on the microscope stage. A special device has also been developed for high-precision measurements of internal diameters of 0.1 mm and larger.

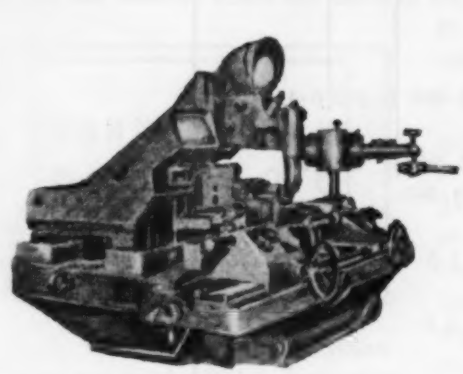

Fig. 2. Universal measuring microscope type UIM-24.

A universal measuring microscope UIM-24 (Fig. 2) for linear and angular measurements of heavy and large-size articles in rectangular and polar coordinates has been developed and produced for the first time in the USSR. The weight of measured articles may amount to 100 kg, and the maximum distance between their centers to 1000 mm. The instrument has sighting and readout projection systems, as well as a visual sighting system. During measurements the image of the stationary measured object is observed on the sighting screen of the projector, or in the microscope field of vision, and the hairlines of the sighting system are set by appropriate displacements of the measuring carriages (longitudinal and transverse). The longitudinal and transverse carriage displacements are read off the respective scale images on the screen. The UIM-24 microscope can measure by means of projection (shadow) methods or by the axial cross section method (using measuring probes). For ease of operation with heavy articles the instrument has a special lifting device.

Fig. 3. Universal measuring microscope type UIM-25.

In 1958-59, an experimental consignment of universal measuring microscopes types UIM-22 and UIM-25 (Fig. 3) was produced for the same types of measurements as those of the large instrument microscope BMI. In contrast to the latter, however, the UIM-22 and UIM-25 microscopes have projection-type optical readout systems and precision linear scales used for measurements. The measuring range has also been extended. The UIM-22 instrument uses an optical micrometer [2] as a readout system whereas instrument UIM-25 uses a special grid scale, which provides a rapid and convenient readout. The UIM-25 scale carries the longitudinal displacement readout system on the left and the transverse readout system on the right. The maximum readout error of the grid scale does not exceed ±0.0015 mm.

Fig. 4. Electrical contact head GK-2 on a horizontal optimeter IKG.

The UIM-25 instrument uses measuring table guides of an original design. The measuring table of the instrument together with the measured article is displaced on four balls in two mutually perpendicular directions. The metallic plates over which the balls roll are half the size of the table displacement. In its movement the table displaces accurate linear scales which determine the amount of its displacement. A similar construction is used in instrument UIM-24, where the measuring carriages are displaced on balls.

Optimeters and comparators. Our plant is mass-producing vertical optimeters type IKV, horizontal type IKG, and special attachments to them, such as a PN-6 projector, a device IP-1 for measuring wire, and three-ribbed table IP-5 for the vertical optimeter, and projector PN-6, vertical centers PP-2, horizontal centers PP-3 and an internal thread-measuring device IP-4 for the horizontal optimeter.

TABLE 1

| Technical Characteristics | Universal Measuring Microscope | | | | |
|---|---|---|---|---|---|
| | UIM-21 | UIM-23 | UIM-24 | UIM-22 | UIM-25 |
| Measurement limits: | | | | | |
| in the longitudinal direction, mm | 0-200 | | 0-500 | 0-100 | 0-150 |
| in the transverse direction, mm | 0-100 | | 0-200 | 0-100 | |
| Angle measuring limits, deg | 0-360 | | | | |
| Calibrations: | | | | | |
| of the linear scale, mm | 1.0 | | | | |
| of the angle-measuring dial, deg | 1.0 | | | | |
| Value of the smallest calibration of the readout system for measuring lengths, mm | 0.001 | | | 0.01 | |
| of the angle-measuring scale, min | 1.0 | | | | |
| Instrument's error in measuring a glass linear scale (with corrections from the instrument's scale certificate), mm | $\pm(0.001+\frac{L}{100{,}000})$ | | | $\pm(0.003+\frac{L}{50{,}000})$ | |
| | where L is the measured length. | | | | |

Since 1960 electrical contact heads GK-2 (Fig. 4) are being produced as auxiliary equipment for the IKG optimeters and the IZM measuring machines for the purpose of measuring internal dimensions of 1 to 13.5 mm. The device consists of a table on which the measured article is placed and a head fixed to a special stand. The tip of the head is chosen according to the diameter to be measured. When an IKG optimeter is used, diameters up to 2 mm are measured directly on the optimeter tube scale (with an appropriate tip), and diameters above 2 mm are measured with the help of block gauges which are lapped to the table try-squares. When the IZM machines are used the reading is taken off the scales. The error of measuring internal diameters amounts to ±0.003 mm.

TABLE 2

| Technical Characteristics | Comparators, mm | |
|---|---|---|
| | IKU-2 | IZV-2 |
| Limits of linear measurements | 0-500 | 0-250 |
| Limits of measured diameters: | | |
| external | 0-225 | 0-250 |
| internal | 13.5-150 | — |
| Smallest division of the readout system | 0.001 | |
| Calibrations of the linear scale | 1.0 | |
| Linear scale measuring limits | 0-100 | |
| Error of the instrument in measuring block gauges (with corrections from the instrument's scale certificate) | $\pm(0.001+\frac{L}{200{,}000})$, where L is the measured length | |

In 1959, a new model of a universal comparator (horizontal displacement gauge) type IKU-2 was developed. The instrument provides measurements of internal and external linear dimensions of various articles, combining the properties of a horizontal comparator and a vertical optimeter. The IKU-2 comparator consists of a base, tail and

measuring heads, and a stage. The measuring head has a projection type scale. The field of vision of the projection screen is shown on Fig. 5. In comparative measurements the readings are taken off the "micron" scale, whose image is shown in the lower part of Fig. 5. In direct measurements hundredths and thousandths of a millimeter are read off the "micron" scale, millimeters are read on the linear scale and tenths on the bisected scale. The images of the linear and bisected scales are shown in the upper part of Fig. 5. All the additional special devices produced for the IKG optimeter can be used with the IKU-2 comparator. Mass production of the IKU-2 comparator will commence in the second half of 1961.

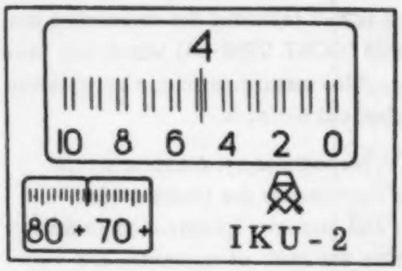


Fig. 5. Image of the field of vision on the screen of a IKU-2 comparator readout system; a reading of 4.5723 mm.

For many years our plant has been producing a vertical optical height gauge IZV-1 intended for contact measurements of external linear dimensions. It is being replaced by a newly developed model of a vertical optical height gauge IZV-2. The new instrument was put into mass production at the end of 1960 and the production of IZV-1 has been discontinued. The new instrument has the following advantages as compared with the previous one: existence of a centering microscope which makes it possible to set the measuring tip to a given point of the measured article, and the absence of a cumbersome oil damper. The IZV-2 gauge can be used as a measuring head with the UIM-21 microscope.

The IZV-1 and IZV-2 gauges are supplied with additional tables type ST-5, ST-6, ST-7 and ST-8, intended for measuring thin sheet components, small details with grooves and protrusions, and medium size diameter threads by means of calibrated rods.

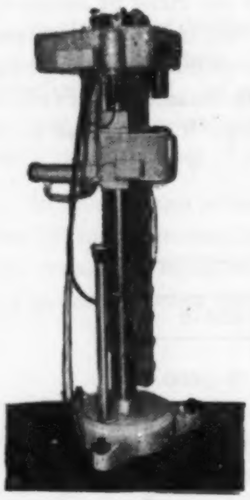

Fig. 6. Cathetometer KM-9.

Cathetometers. Our plant pays considerable attention to the production of cathetometers intended for measuring vertical segments on objects which cannot be reached directly. At present the plant mass-produces a cathetometer type KM-6 which consists of a vertical stand, a tripod, a measuring carriage, a telescope and a measuring microscope. The telescope objective is supplemented by one of the four attachments, thus providing the possibility of measuring articles placed at different distances from the instrument. Its readout system consists of a microscope with a grid scale (the grid scale is similar to that of the UIM-25 measuring microscope), by means of which readings are taken on a glass scale calibrated in 1 mm.

Experimental models of cathetometers KM-8 and KM-9 (Fig. 6) have now been made. They have a considerably larger range than cathetometer KM-6. In contrast to the latter cathetometer, in which the sighting and readout systems have separate eyepieces, and the ends of the air bubble in the level are observed through a magnifying glass, in the KM-8 cathetometer the sighting crosshairs of the telescope, the image of the air bubble, the millimeter scale and the grid scale are projected into the field of vision of a single eyepiece, thus increasing considerably the productivity of the measuring process and making the instrument much easier to handle.

Fig. 7. Superposition spherometer IZS-9.

The KM-9 instrument also has a single field of vision, but contrary to the KM-8 cathetometer, in which the eyepiece is displaced with the measuring carriage, the KM-9 eyepiece remains stationary. Mass production of the KM-8 cathetometer will start in 1961 and that of the KM-9 type in 1962.

Other measuring instruments. The plant mass-produces machines type IZM-10M and IZM-11, intended for measuring internal and external linear dimensions of various articles. The external measuring range of the IZM-10M machine is 0 to 1000 mm, and of the IZM-11 machine is 0 to 2000 mm. The supports of this machine have been redesigned and its table made lighter. The newly designed supports provide the possibility of a transverse displacement of the measured article, and are convenient for checking large-size gauge blocks. On special order the plant makes measuring machines IZM-12 and IZM-13, which have a range of 0-4000 and 0-6000 mm respectively.

Various direct linear measurements can be made on the horizontal comparator IZA-2 which is mass produced by the plant. Among other things the instrument can be used for measuring distances between spectral lines on negatives of spectrograms, measuring various scales, grids, etc. The instrument covers a range of 0-200 mm, the helical micrometer of its microscope is calibrated in 0.001 mm. The error of the instrument in measuring a glass linear scale (with corrections from the instrument's scale certificate) amounts to 0.9-1.6 $\mu$, according to the length of the measured article.

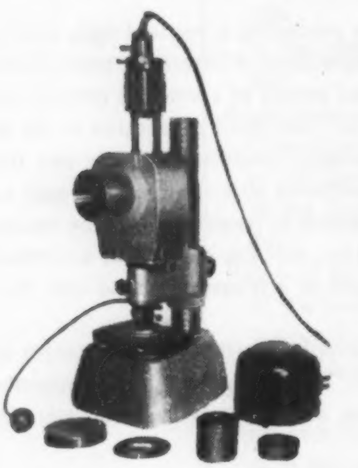

Fig. 8. Ultraoptimeter IKP-2.

The plant mass-produces spherometer IZS-7 intended for measuring the radii of curvature of the main test lenses OPS (GOST 2786-54) which are widely used in the optical-mechanical industry. The instrument can also measure the radii of various convex and concave spherical surfaces.

In 1960, experimental models of the superposition spherometers type IZS-8 and IZS-9 (Fig. 7) were made. The instruments are intended for measuring the radii of curvature of convex and concave spherical surfaces in heavy articles. According to normal practice the radii of curvature are measured by means of the spherometer indirectly, since the spherometer measures the rise in the spherical segment and the radius of curvature is then calculated from that rise and the diameter of the measuring circumference employed. The IZS-8 spherometer measures the spherical rise directly on a linear millimeter scale attached to the measuring rod of the instrument. This scale is read off by means of a measuring microscope with an eyepiece screw micrometer. Measurements of the IZS-9 spherometer are made by means of a differential method. Its readout device consists of a dial indicator calibrated in microns. The instruments are supplied with exchangeable measuring rings 100, 150, 220, and 300 mm in diameter. The error in measuring the radii of spherical surfaces depends on the size of the radius and the diameter of the measurement ring. It is intended to start mass production of these instruments in 1961.

TABLE 3

| Technical characteristics | Cathetometers | | |
|---|---|---|---|
| | KM-6 | KM-8 | KM-9 |
| Vertical measuring limits, mm | 0-200 | 0-500 | 0-1000 |
| Distance of the measured article from the telescope objective, mm | 140-150<br>340-380<br>500-625<br>730-969 | 470-670<br>610-1000<br>890-2000<br>2000-∞ | |
| Calibrations of the telescope's cylindrical level (per 2 mm), sec | 20 | 4 | |
| Maximum error on the grid scale of the readout system, mm | ±0.0015 | 0.0015 | |
| Error of the instrument in measuring a glass linear scale, mm: | | | |
| distance from the measured scale of 140-150 mm | ±0.006 | — | |
| distance from the measured scale of 340-380 mm | ±0.010 | — | |
| distance from the measured scale of 500-625 mm | ±0.014 | — | |
| distance from the measured scale of 730-969 mm | ±0.021 | — | |
| distance from the measured scale of 2000 mm and more | — | ±(0.03-0.04) (calculated values) | |

TABLE 4

| Technical characteristics | Spherometers | | |
|---|---|---|---|
| | IZS-7 | IZS-8 | IZS-9 |
| Range of radii of the basic test lens pairs, OPS, mm: | 37.5-750 | | — |
| Range of measured spherical surface radii, mm: | 10-1000 | 80-∞ | |
| Smallest calibration of the readout device, mm: | | 0.001 | |
| Calibrations of the linear scale, mm: | | 1.0 | — |
| Error in measuring the radii of test lens pairs, %: | ±0.02 | | — |
| Error in mesuring spherical surface radii, %: | | | |
| between 10 and 37.5 mm: | ±0.07 | | — |
| between 37.5 and 1000 mm: | ±0.04 | | — |
| between 80 mm and ∞: | — | ±(0.02-0.06) | |

At the end of 1960 an experimental model of a projection optimeter calibrated in 0.2 mm (utraoptimeter) type IKP-2 (Fig. 8) was made. The instrument is intended for contact measurements of external linear dimensions by a comparison method. Its maximum range is 200 mm. The measurements are read off a scale projected onto a screen. The scale covers a range of ±0.025mm. The calculated maximum error of the instrument is ± [0.04 + (L/2000)] μ, where L is the number of scale divisions. Mass production of this instrument will begin in 1962.

In recent years several instruments for special application have been made, such as the MIV-1 and MIV-2 machines [3] for measuring the parameters of guide screws 2000 mm long, optical contactless micrometers type OBM-2 [4] for measuring thickness up to 50 mm by a countless method, an instrument type PGVK for checking shaft screws, and a number of other precision measuring instruments.

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# NEW ANGLE-MEASURING TABLE WITH AN INDUCTION TRANSDUCER

E. M. Goloul'nikov, M. I. Kochenov, A. Ya. Pelika,

and V. S. Chaman

Translated from Izmeritel'naya Tekhnika, No. 4,
pp. 9-13, April, 1961

The main drawback of instruments for measuring angles by means of calibrated dials is the almost complete impossibility of using them for automatic measuring of angles and angular displacements. In this connection several organizations are developing electrical methods of measuring angles by means of automatic and nonautomatic induction angle measuring devices intended for various purposes. In order to investigate experimentally induction methods of measuring angles the Special Design Office (OKB) of the Moscow City Sovnarkhoz (Council of National Economy) designed and made an angle-measuring table whose principle of operation is shown in Fig. 1.

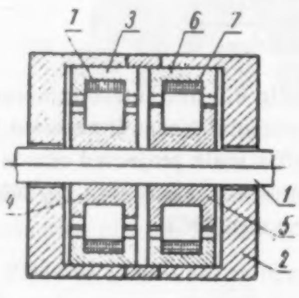


Fig. 1.

Two toothed rings 4 and 5 are fixed to shaft 1, and two other rings 3 and 6 with the same number of internal teeth as 4 and 5 are fixed to the casing 2. The grooves of these rings carry similar coils 7. A gap is left between the crests of the shaft and casing teeth. The rings are placed in such a manner that when, during the rotation of the shaft with respect to the casing, the crests of the teeth in ring 4 pass oposite those in ring 3, the crests of the teeth in ring 5 pass opposite the spacings in ring 6. At this instant the impedance Z will be at its maximum in the coil of ring 3 and at its minimum in that of ring 6. The value of impedance Z is:

$$Z = \sqrt{R^2 + X^2}\ . \quad (1)$$

where R is the resistance, and X is the reactance of the coil.

When shaft 1 is rotated further, impedence Z increases in coil 6 and decreases in coil 3. The values of R and X change simultaneously and in the same direction. It is possible by means of an ordinary differential circuit to determine the difference in the impedence of the two coils, for instance, by comparing the voltages across each of them. The difference of these voltages will change with respect to the angle of rotation of the shaft according to a sinusoidal law with a period of $2\pi/z$ where $\underline{z}$ is the number of teeth in the ring. It is obvious that the number of zero values in the difference of the two voltages in one revolution of the shaft will equal 2z, thus making it possible in theory to divide one revolution of the shaft into 2z angular parts. The current in the coils is produced simultaneously by all the teeth in the shaft and the casing. Since the total error of divisions in each ring is equal to zero, a very high uniformity of angular intervals between the adjacent zero values of the difference in the voltages across the coils is obtained.

The value of impedance Z of each coil of the angle-measuring device is determined mainly by the value of the magnetic circuit reluctance, which in turn is determined by such purely geometrical factors as the shape and mutual position of the teeth and spaces in the shaft and casing rings. Errors in the shape of teeth, inaccurate displacements of the shaft, deviations from a coaxial position of the rings, etc., cause errors in the position of the difference voltage zero values. Moreover, the error in the mutual position of adjacent "zeros" will be larger than that in the mutual position of odd and even "zeros."

Therefore, it is advisable to use induction angle-measuring for dividing the circumference into $\underline{z}$ and not 2z equal parts.

The main sources of error in an induction angle-measuring table consist of: a) errors in the positioning of the teeth in the shaft and casing rings; b) deviation from the coaxial position of the shaft ring with respect to the casing ring; c) wobble of the shaft rings; d) variations in the supply parameters (mains voltage, its waveform and frequency); e) error in determining the position of zero points (errors in the null-indicator, in the readout, etc.).

This article deals with the qualitative analysis of the degree to which various errors affect the accuracy of the induction angle-measuring device.

The degree of magnetic coupling between the shaft and casing rings will remain constant for a definite mutual position of the teeth over a complete revolution, providing there are no errors in the positioning of the teeth. These errors, which are inevitable in actual rings, usually have a sinusoidal nature, and therefore it is natural to assume that errors in the position of the difference voltage zero values will also have this characteristic. This assumption was confirmed by tests of the induction angle-measuring device.

The deviation from coaxiality in the shaft and casing rings does not produce in the position of the difference voltage zero values, providing their is no error in the positioning of the teeth. When the above errors exist, however, the lack of coaxiality produces in the position of zero readings additional errors whose nature is similar to the errors due to the positioning of the teeth.

The errors in zero readings due to the wobble of the shaft with respect to the casing are of a somewhat different nature. The wobble consists of regular displacements due to the geometrical axes of the shaft and casing not coinciding, and to irregular displacements due to free play in the shaft bearings. The shaft wobble in the radial direction can be resolved into two components consisting of the displacement of the shaft tangentially and normally to the crests of the teeth. Only the first component can change the reluctance of the magnetic circuit, the second will not change the reluctance, and hence the induction of the coils, providing the wobble is small as compared with the gap between the teeth.

Thus, the wobble also leads to errors in the angular position of the zero balance points; moreover, this error may have either a systematic or, which is more likely, a random characteristic, depending on the relation between the value of the wobble caused by the lack of coincidence in the axes and the wobble due to free play in the shaft bearings.

The errors of an induction angle-measuring device due to the above causes may be reduced first of all by raising the accuracy in making and assembling the shaft and casing geared rings. The effect on the accuracy of the angle-measuring device of the errors due to the positioning of teeth, shaft wobble, lack of coaxiality in the shaft and casing, are reduced if the air gap between the shaft and casing teeth is increased. However, this reduces considerably the sensitivity of the device which cannot always be compensated by raising the sensitivity of the multiindicator electrical circuit.

Irregular random errors are also provided by the electrical circuit for counting the zero balance point of the bridge and by the indicating instrument itself (microammeter).

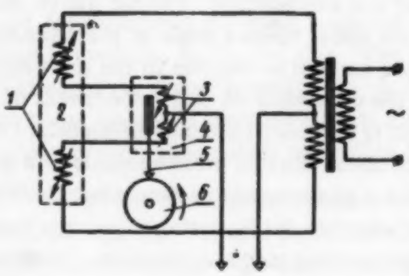


Fig. 2.

The systematic errors, contrary to the random ones, can be determined experimentally over a complete revolution of the shaft and compensated in the bridge circuit of the device. The schematic of such a compensating device is shown in Fig. 2. Here 1 is the induction coil of the angle-measuring table 2, and 3 are the auxiliary induction differential transducers of compensator 4, whose measuring rod 5 rests against cam 6, which is fixed to the shaft of the angle-measuring device. The profile of the cam is made in such a manner as to produce, by means of the measuring rod displacements, variations in the compensator inductance which would provide the required shift in the position of the bridge balance points. In compensating errors of a sinusoidal nature the cam is made circular and mounted eccentrically on the shaft.

One of the basic parameters of an induction angle-measuring device is its sensitivity, in our case the ratio of the output instrument pointer end displacement to the angular displacement of the shaft.

The sensitivity of the device as a whole depends mainly on that of the induction transducer connected to the bridge circuit and on the null-indicator electrical circuit. In designing the instrument it is advantageous to provide a maximum sensitivity for the transducer, in our case for the induction angle-measuring device, and to have the gain in the second stage of the circuit consisting of the null-indicator as low as possible.

The sensitivity of the measuring device based on a bridge depends in the first instance on the voltage feeding the bridge. However, it is normally impossible to raise this voltage above 15-20 v, owing to the saturation of the magnetic circuit and overheating of the windings.

The constructional elements of the transducer which determine its sensitivity consist in the first place of the size of the air gap between the shaft and casing teeth, the number of teeth and their shape. The sensitivity is lowered by increasing the air gap or the number of teeth, but it can be raised to the required level by means of an amplifier.

The manner in which the shape of the teeth and spaces affect the sensitivity should be explained. Both calculations [1] and experimental results have shown that the greatest sensitivity of an induction angle-measuring table is attained (providing the remaining conditions do not change) in the position of the shaft and casing teeth edges shown in Fig. 3, with the spacing between the teeth considerably larger than their width (at least twice as large). However, the negative effect of the shaft radial wobble on the accuracy of the device is most pronounced precisely in this position of the teeth edges. Therefore, it is advantageous to place the bridge zero balance point in the area of a small overlap of the teeth. In this case the sensitivity will be somewhat decreased but the accuracy will rise considerably. The most advantageous overlap of the shaft and casing teeth depends on the shaft radial wobble and the free play in its bearings, and should be selected experimentally for each angle-measuring device.

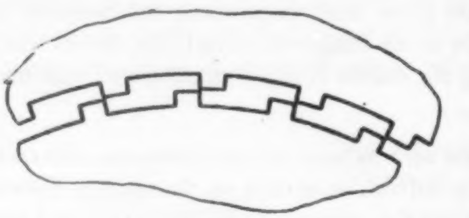

Fig. 3.

The constructional schematic of the angle-measuring table developed and produced by the OKB is shown in Fig. 4. Casing 1 carries two rings 2, each of which has 360 internal teeth. The upper ring can be displaced with respect to the lower and secured in the required position by means of set-screws. Shaft 3 with its two rings 7 which have 360 teeth each is fixed on rolling bearings to the casing. The rotating stage 5 is fixed to rod 4 which is mounted on rolling bearings in the cylindrical opening coaxial with the external surface of the shaft. A vernier adjustment of the rod is obtained by means of a differential micrometer screw. Lever 6 is fixed to the collar of shaft 3 in the required position by means of a clamp. The end of the lever at a distance of 412.5 mm from the axis of the shaft carries a linear scale which can be seen through a microscope with a spiral vernier calibrated in microns. The angle of rotation of lever 6 and hence of shaft 3 in the range of $\pm 1°$ is measured by means of a linear scale and the miscroscope. For the above length of the lever each division of the spiral vernier scale of the microscope corresponds to 0.5". The whole number of degrees in the shaft rotation is read off the zero values in the difference of coil impedances of the induction device. The readout is obtained from the differential (bridge) circuit, which is connected for nonautomatic measurements to a pointer instrument. This circuit makes a phase-sensitive detection possible (the direction of the current flowing through the registering instrument changes when the bridge balance point is crossed). For automatic angle measurements electrical command pulses should be transmitted to the appropriate elements of the angle-measuring devices.

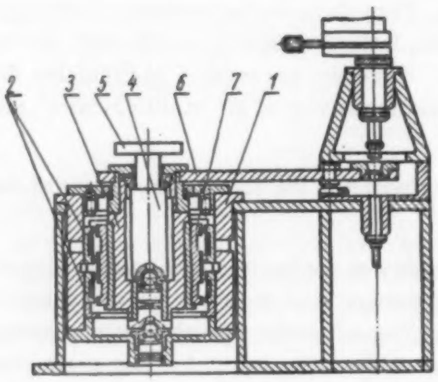


Fig. 4.

The electrical circuit of the null-indicator should possess in addition to the normal requirements for its stability several special features. Thus, it must have a sufficient gain; it must have provision for filtering out the harmonic voltage components in the bridge supply; it should be possible to limit the current flowing through the measuring instrument at a maximum permissible value for the microammeter.

The schematic of the null-indicator circuit which was specially developed for the above angle-measuring device, and which meets all the above requirements, is shown in Fig. 5.

The differential bridge circuit consists of two windings of the supply transformer T1, and the two coils of the induction transducer IT. The voltage from the diagonal of this bridge is fed to an amplifier.

RC-filters with an adjustable maximum attenuation frequency are provided between the first and second and the second and third stages of the amplifier (tubes 6N2P and 6N1P). The first filter is tuned to the second harmonic of the bridge supply voltage, i. e., to 100 cps, and the second filter to the third harmonic, i. e., 150 cps.

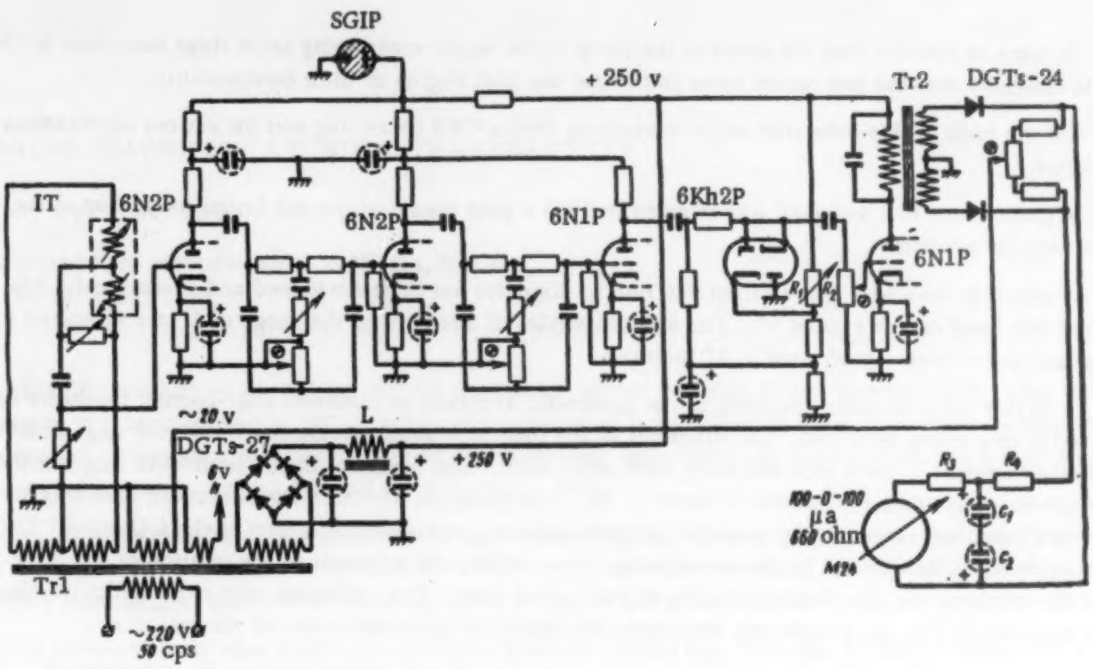


Fig. 5.

Between the third and fourth (output) stages a circuit for limiting the amplified bridge unbalanced voltage is provided. It consists of a double diode type 6Kh2P. The limiting level is selected by means of resistor $R_1$ in such a manner that, for a maximum amplified unbalanced voltage at a maximum circuit sensitivity controlled by resistor $R_2$ (when the pointer is in the center position), the measuring instrument pointer does not go beyond the end of its scale.

The second half of the double triode 6N1P is used for the output stage. The anode circuit of this tube is connected to the output transformer T2, whose secondary winding is connected to a phase-sensitive rectifier consisting of two DGTs24 diodes, and then to a ±100 μa microammeter type M24. For counting the zero balances of the bridge only the middle, zero, calibration of the instrument is used. Since the instrument's scale is nonlinear it cannot be used for measuring the shaft angles of rotation. In order to raise the time constant of the instrument an output T-type filter is used ($R_3$, $R_4$, $C_1$ and $C_2$). The reference voltage is supplied to the phase-sensitive rectifier from a special winding of the power transformer. In order to eliminate the possibility of a phase difference between the input of the phase-sensitive rectifier and its reference voltage, the unbalanced voltage is fed to the amplifier input with a certain present phase-shift controlled by means of resistor $R_5$.

After the required adjustment of the appropriate circuit elements, the rotation of the angle measuring device shaft through 0.25" produces a deflection of the microammeter pointer by one division (5 μ a) to the left or the right of the zero position. The zero reading of the instrument is not affected by a supply voltage variation ± 10% from the normal voltage. Random voltage jumps are completely eliminated by supplying the set through a ferroresonance stabilizer.

When the angle-measuring device shaft is rotated slowly the microammeter pointer does not exceed the extreme positions of its scale when the bridge unbalance passes through its maxima. When the shaft is rotated rapidly the pointer does not deviate appreciably from zero.

The accuracy of the indication angle-measuring table was checked by means of a flat rule fixed to the table and two nozzles mounted on the instrument casing and connected to a double-tube pneumatic measuring instrument.

Repeated tests were carried out for a complete revolution of the shaft in intervals of 30, 60, and 120°. The value of the accumulated errors in the shaft rotation angles did not exceed 5.3". These values characterize the systematic errors of an angle-measuring table made without a cam compensator. Random errors in a single measurement of an angle did not exceed 2".

In view of the fact that the errors in the pitch of the angle-measureing table rings amounted to 150", it is possible to conclude that the test results have confirmed the high degree of their compensation.

On the basis of this induction angle-measuring device OKB measuring sets for various applications have been developed.

A goniometer thus designed was awarded in 1960 a gold medal at the All-Union exhibition of the achievements of our national economy.

A dividing head with geared rings 180 mm in diameter has been developed and constructed. The measurement errors of this head do not exceed 5". The rotation angles of this head in the range of 1" are measured by means of a wedge and screw device graduated in 5" intervals.

A device for automatic checking of the kinematic accuracy of precision gear-cutting machines has been developed and is now being produced. The diameter of the induction angle-measuring transducer rings fixed on the machine table amount to 1000 mm and carry 1000 teeth each. The diameter of the transducer ring mounted on the machine spindle is 75 mm, and number of teeth is 50. The principle on which the automatic checking of the gear-cutting machine's kinematic accuracy by means of induction transducers is based consists of the following. The electrical pulses automatically supplied by the transducers at certain angular intervals in the rotation of the table and the spindle of the machine are recorded on a uniformly propelled film. The variations with time in the misalignment of pulses supplied by the two transducers determine the degree of kinematic error of the machine.

An instrument for measuring the pitch of worm gears and gear cutters has also been developed.

In solving certain metrological problems it is very convenient to use the induction angle-measuring transducer for automatic measurements of long distances and linear displacements. The value of a linear displacement can be determined by the rotation angle of the transducer driven by a moving table. The testing of such devices under laboratory conditions produced very satisfactory results.

At present a device is being tested for measuring linear displacements of a coordinate boring machine. The quality of operation of such a device can be greatly influenced by the vibrations of the machine, uneven movement of the table and other circumstances, which produce a slipping of the rule which bears on the operating surface of the transducer casing.

An inductive angle-measuring device capable of providing a very high accuracy of measurements may be used in designing various goniometric instruments. It is already possible to make gonimetric devices which automatically provide discrete signals in a rotating shaft at intervals of 20-30'.

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# DETERMINING HARDNESS AT HIGH TEMPERATURES

N. P. Slavina and A. V. Smirnov

Translated from Izmeritel'naya Tekhnika, No. 4,
pp. 14-16, April, 1961

Alloy ÉI437B normally employed for making gas turbine blades was used in our investigations. This alloy was selected because it is heatproof up to 800°C, need not be protected from oxidation when its hardness is measured up to this temperature, it has been sufficiently studied for its strength with respect to temperature, has a high recrystallization temperature and hence can be used up to its creep point.

Samples for measuring hardness consisted of 1-1.5-m-long forgings of an octagonal cross section. The forgings were cut into samples 9-14 mm thick with an area of 2500 mm² and then machined up to 5-6th grade of surface finish. Next, they were heat-treated and polished up to the 10th grade of surface finish.

Hardness measurements were made on a universal hardness gauge (Fig. 1) by the Vickers method with a 20 kg-wt load. The samples were heated in a vertical muffle oven 1 with the OKh25Yu5 tape 3 wound over a quartz tube 2.

The temperature was controlled by means of a rheostat and measured with a chromel-alumel thermocouple 4. Sample 5 was placed inside the oven on a quartz table 6, which can be turned so as to make indentations at different points of the sample. For one fixing of the sample, 40 indentations could be made. Point 7 was fixed to quartz extension 8.

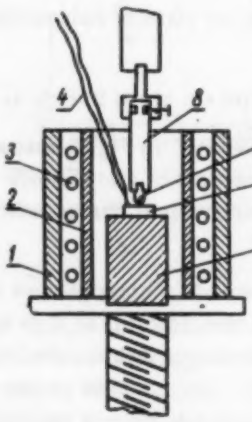


Fig. 1.

A. Vickers diamond pyramid was found to be suitable for the shape of the trip. This shape was selected experimentally by establishing the relation between the HV hardness numbers, which were obtained by pressing in a square pyramid, and the toughness characteristics $\sigma_s$ and $\sigma_b$.

The sample was heated up at the rate of ~4°C/min, kept at the required temperature for 30 min, and then subjected to a gradually applied load of 20kg-wt. The depth of the indentation was measured by a dial-type indicator calibrated in steps of $2\mu$. Readings were taken at 600°C immediately after applying the load and after its application for 10, 20, 30, and 60 sec. From these data the optimum duration of applying the load before taking readings was found to be 30 sec.

The effect of the extension rod on the accuracy of measurements was negligible, since a quartz rod was used.

The temperature of the upper part of the oven was less than 10°C below the central part. This did not affect the temperature of the sample, which was 9-14 mm thick and placed in the middle of the oven.

The hardness numbers of alloy ÉI437B for various temperatures were determined by the following three formulas: 1) by the depth of the unrestored indentation $h_t$, measured on the instrument dial indicator with the tip pressed into the heated sample under a constant load of P = 20 kg-wt

$$H_{h_t} = \frac{P}{h_t^2}\ \text{kg-wt/mm}^2. \tag{1}$$

The measurement of $H_{ht}$ provides an idea of the resistance of the material to an elastoplastic deformation at the test temperature. In order to be able to compare the values of $H_{ht}$ with the hardness numbers calculated from the diagonal of the indentation, it is necessary to have the same dimensions, hence, in formula (1) the load is referred to the square of the depth ($h^2$).

2. By the diagonal $d_{20}$ of the restored indentation measured after the cooling of the sample to 20°C:

$$HV_{d_{20}}=2\sin\frac{\alpha}{2}\frac{P}{d_{20}^2}\ \text{kg-wt/mm}^2, \tag{2}$$

where $\alpha$ is the angle between the opposite faces of the pyramid at the apex of the diamond tip, which in our case is 136°.

This measurement provides an idea of the residual deformation of a cooled sample due to its loading in a hot state.

3. By the diagonal $d_t$ of the indentation calculated from the unrestored depth $h_t$ which was measured at the test temperature.

$$HV_{d_t}=2\sin\frac{\alpha}{2}\frac{P}{d_t^2}\ \text{kg-wt/mm}^2. \tag{3}$$

This measurement, however, is not a simple recalculation from the value of $h_t$ which was measured on determining $H_{ht}$. In a geometrical calculation of a regular square based diamond pyramid with an angle of 136° at the apex

$$d = kh, \text{ where } k = 7.$$

In our case the value of k, equal to 7.4, was obtained experimentally as a mean of 47 measurements of the alloy hardness at a temperature of 20°C. Coefficient k accounts for the actual shape of the tip and the effect of this shape on the tested material; hence, it should always be determined experimentally. Thus the measurement of $HV_{d_t}$ has an independent value obtained from the formula

$$HV_{d_t}=2\sin\frac{\alpha}{2}\frac{P}{(kh_t)^2}\ \text{kg-wt/mm}^2. \tag{3a}$$

It represents, in the same manner as $H_{h_t}$, the elastoplastic resistance of the material in a hot state of indentation by the pyramid.

TABLE 1

| $H$ | Quadratic mean error of measurement | | |
|---|---|---|---|
| | $\mu$ | % | % of H |
| $H_{h_t}$ | 3,68 | 6 | 12 |
| $HV_{d_{20}}$ | 5,20 | 1,5 | 3 |
| $HV_{d_t}$ | 3,68 | 6 | 12 |

The measurement resusits are given in Fig. 1.

It will be seen form curve $H_{h_t}$ in Fig. 2 that above a temperature of 700°C the hardness of alloy ÉI437B falls sharply, and hence its other mechanical characteristics also fall at that temperature.

Calculations from (1) provide a clear picture of the variations in the properties of the material at high temperatires, and if necessary make it possible to recalculate the hardness numbers from (3). The hardness values of $HV_{d_{20}}$ and $HV_{d_t}$ practically coincide up to a temperature of 300°C, since the difference in the hardness numbers is of the same order as the errors of measurements (3-4%). With a further rise of temperature the difference increases and at 700°C it attains 35-40%. Hence, if hardness at high temperatures is to be considered as a property of the material, it should be determined from the data obtained from a sample in a hot state.

Calculations from (3) require a preliminary experimental determination of the ratio d/h for the given material and tip.

The lack of parallelism between curves $H_{h_t}$ and $HV_{d_t}$ shows that the ratio d/h is not constant even for the same material and tip, and changes with temperature.

For the calculation of the quadratic mean deviation (S) 10 groups of measurements were made with 8 measurements in each group. Table 1 gives the quadratic mean error (S) in measuring h and d, expressed in microns and percentages. The quadratic mean division in calculating the hardness numbers $H_{h_t}$, $HV_{d_{20}}$ and $HV_{d_t}$ are shown in the last column.

If we should add to the error in determining $HV_{d20}$ the error due to the compression of the sample in cooling, which has a nonlinear temperature relationship and rises with the temperature expansion coefficient of the material under test, we would obtain a considerable decrease in the difference between $HV_{d20}$ and $HV_{d_t}$ (see Fig. 2).

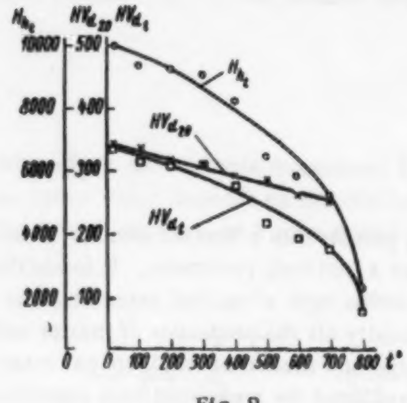


Fig. 2.

Table 2 gives the values of $\sigma_s$ and $\sigma_b$ at different temperatures for samples of the same alloy ÉI437B measuring $d_0$ = 8 mm and $l_0$ = 40 mm and obtained for a constant rate of loading.

TABLE 2

| t, °C | $\sigma_s$, kg-wt/mm² | $\sigma_b$, kg-wt/mm² | $\delta_5$,% | Note |
|---|---|---|---|---|
| 500 | 66.0 | 77.8 | 6.0 | In the first two cases $\delta_5$ was calculated from the sample, in the remaining cases from thr stress diagram |
| 600 | 62.0 | 76.5 | 7.0 | |
| 700 | 62.5 | 72.5 | 1.26 | |
| 800 | 54.2 | 66.2 | 2.8 | |

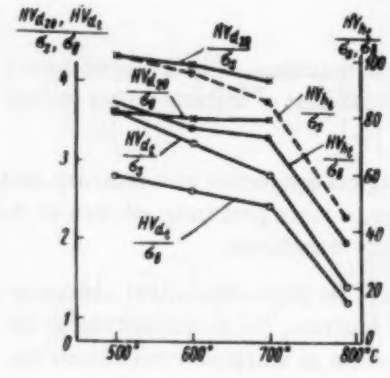


Fig. 3.

Figure 3 shows the relation of $H_{ht}$, $HV_{d20}$ and $HV_{d_t}$ to the values of $\sigma_s$ and $\sigma_b$ at the same temperatures.

Conclusions. 1. The measurement of hardness at high temperature is an approximate speedy method which in many instances may replace the more protracted toughness tests at high temperatures.

2. Hardness at high temperatures can be measured by means of ordinary hardness guages with attachments in the form of heating and protecting devices, extension rods for fixing the tips and tips made of heat-resisting materials with a small temperature expansion coefficient. A diamond tip can be used in air with a loading of 20 kg-wt at temperatures not exceeding 700°C. Abrupt temperature variations are not permissible, since they produce cracks in the diamond.

3. The hardness numbers for high temperatures can be calculated from three formulas for $H_{ht}$, $HV_{d20}$ and $HV_{dt}$. However, the values of these measurements and their errors are not comparable to each other.

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# ELECTRICAL MEASUREMENTS

## PROVISION OF FREQUENCY TRANSDUCERS FOR ALL ELECTRICAL AND NONELECTRICAL QUANTITIES *

P. V. Novitskii

Translated from Izmeritel'naya Tekhnika, No. 4,
pp. 16-21, April, 1961

Various measured quantities are in practice transformed in the measuring process into a limited number of output parameters. Mechanical displacements was historically the first type of such a (unified) parameter. It forms the basis of mercury thermometers, spring manometers, pointer voltmeters, etc. Another type of unified parameter consists of the value (amplitude) of electrical current or voltage. At present practically all the properties of matter and energy can be converted by means of electrical transducers into current or voltage and measured on electrical measuring equipments. For this purpose over 25 systems of transducers have been developed for measuring both electrical (rectifiers, thermal converters, surge coils, shunts, electrical and magnetic probes, Hall transducers, etc.) and nonelectrical (photocells, themocouples, resistive, inductive and capacitative impedance transducers, etc.) quantities. All these transducers are based on amplitude modulation of electromagnetic processes and have a continuous characteristic.

At present, with the requirements of feeding measurement results into digital machines, it becomes necessary to develop discrete measuring systems. The unified parameter of such systems should consist of discrete pulses instead of an analogue value of current or voltage.

As a temporary measure this problem can be solved by using analogue to digital converters with ordinary measuring devices. Many organizations are now developing such converters. However, a more promising solution of this problem consists in developing directly measuring,discrete, in particular, frequency transducers.

As the result of the work conducted in recent years at the problems laboratory for physicotechnical measurements of the electrical measurements department of the Leningrad Polytechnical Institute, the author arrived at the conclusion that frequency transducers can be produced to measure in a manner similar to amplitude transducers the most varied physical quantities. It can even be expected that eventually the frequency transducers will develop to a point when the number of their types will exceed the number of amplitude transducer types known at the present time.

The basic feature of all the frequency transducers consists in using self-oscillatory systems in a generating condition. The measured value is sensed in this arrangement by the tuned circuit elements of the oscillatory system, thus determining the generated frequency. As the result of this the output pulse repetition frequency becomes a single-valued function of the measured quantity. In many instances a high degree of linearity for this function may be obtained, thus providing the value of the measured quantity by counting the number of pulses per unit of time, and its time integral by counting the pulses over an arbitrary time interval.

The great simplicity of accurate digital integration constitutes another great advantage of frequency transducers.

The self-oscillatory systems of frequency transducers may use in their excitation circuits various types of amplifiers, including mechanical, pneumatic, hydraulic and electrical amplifiers. However, the characteristic of transducers according to the type of amplifier they use is not fundamental. A more fundamental characteristic, which determines the functioning of the frequency transducers consists in the type of the passive tuned circuit which, in conjunction with the exciting amplifier, forms the self-oscillatory system of the transducers.

The tuned circuits which can serve for designing frequency transducers can be divided into five groups: 1) devices with lumped electrical parameters; 2) devices with lumped mechanical parameters; 3) devices with a variable time delay; 4) devices with linearly distributed parameters; 5) devices with volumetrically distributed parameters.

*From the paper read at the second inter-university conference on production automation, held in Baku in October, 1960.

The principle od operation of each group of these frequency transducers can be illustrated by a number of examples.

1. Frequency transducers with lumped electrical parameters consist of electron oscillators, whose tuned circuit comprises parametric transducers of resistive, inductive and capacitative impedances. In RC oscillators with a variable resistor (Fig. 1a) the relation between frequency and the relative variation of resistance has the form of:

$$f_x=f_0\frac{1}{\sqrt[n]{1+\varepsilon_R}}\approx f_0\left(1-\frac{1}{n}\varepsilon_R\right), \tag{1}$$

where $f_x$ is the variable frequency; $f_0$ is the initial frequency; $\varepsilon_R = \Delta R/R$ is the relative variation of resistance; n is an index which depends on the configuration of the tuned circuit, and is equal to 2 for a Wien bridge, to 3 for a three-section RC network, to 3 for a twin T-bridge, and to 4 for a 4-section RC network.

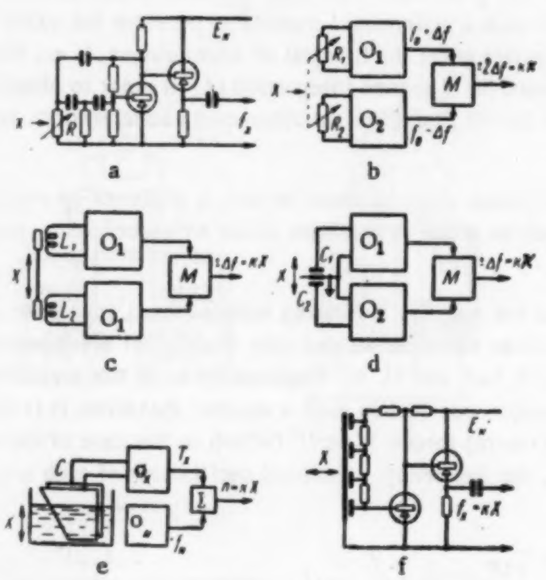

Fig. 1.

The transformation function of such a frequency transducer is not strictly linear; hence, for a deviation of 10% and n equal to 2, 3, and 4, the error due to nonlinearity amounts in digital readout to 13, 16, and 18% respectively, and decreases with a smaller deviation. Nevertheless, such transducers are already being used in practice [1].

A pronounced decrease in the nonlinearity error is attained by using a differential resistance transducer and two oscillators $O_1$ and $O_2$ (Fig. 1b), with the frequency of one of them increasing while that of the other decreases. By means of a ring modulator M their difference frequency is obtained, which is proportional to the measured value. The error due to nonlinearity in this case is decreased to the value obtained in a differential resistance transducer of an unbalanced bridge circuit.

The limitation of this frequency transducer circuit consists in the necessity of obtaining a deviation of 5-15% for a relative variation of resistance amounting to 10-60%. Therefore, it is impossible to use in this system, for instance, wire strain gauges whose resistance variation does not exceed 0.1%. This difficulty is overcome by using split-phase oscillators with an artificial 90° phase shift [2]. The nonlinearity error in this instance amounts to ±0.25% for a frequency deviation of ±10%.

In frequency transducers consisting of LC oscillators with a variable capacitance or inductance, the relation between the frequency and the relative variation of capacitance or inductance also follows the above-mentioned formula with an index n varying between 2 and 8 according to the relative sensitivity of the transducer. However, the inductance of capacitance of parametric transducers with a variable air gap $\delta$ is in turn inversely proportional to the value of this gap, which makes the conversion function assume the form of:

$$f_x=f_0\sqrt[n]{1+\delta\cdot k}, \tag{2}$$

which has a nonlinearity error of 4.5% for a frequency deviation of 10%. If differential transducers providing a difference frequency of two oscillators are used (Fig. 1c and d), this error is reduced to 0.5%. At the same time, the temperature error according to the data obtained by the author is also reduced to 0.2%/10°C.

When capacitative transducers with a variable area obtained by means of slanting plates are used (Fig. 1e), it is easy to obtain a square-law relationship between capacitance C and the measured value X. In this case the period $T_x$ of the generated oscillations is in theory a linear function of the measured value. Its coverage by reference frequency $f_N$ pulses provides a simple highly accurate digital-pulse system.

A capacitative transducer, one of whose plates is sectionalized (Fig. 1f), provides an oscillator frequency which is proportional to the measured value, i. e., is in theory a linear function of the measured value.

One of the advantages of this system consists in the simple adding of readings obtained from different measured objects. For this purpose it is sufficient to connect the adding counter, which in this case serves as an output indicating instrument, to the oscillators of each of the measured objects in turn.

2. Frequency transducers with lumped mechanical parameters, those of the second group, can be illustrated by the following examples.

A pendulum integrating accelerometer [3] contains a frequency transducer in the form of a generator (similar to a tuning-fork generator) whose frequency is determined by the natural frequency of the pendulum made similar to the pendulum used in watches. If the pendulum is perfectly balanced its frequency does not depend on the effect of external accelerations; however, if the pendulum is unbalanced, the relation of its frequency to the measured acceleration $\ddot{x}$ assumes the form:

$$f_x = f_0 \sqrt{1 + k \cdot \ddot{x}}. \quad (3)$$

In order to avoid nonlinearity, a difference frequency of two generators with their pendulums unbalanced in opposite directions (Fig. 2a) is used. The frequency variation of such a differential transducer provides the value of the acceleration, and the counting of the total number of output pulses gives the integral of acceleration, i. e., the velocity of the transducer in space. The same principle can be used for a second integration [4] in order to obtain the value of displacement in space, i. e., the instrument provides in a digital form simultaneously acceleration, velocity and displacement of the movement under consideration.

In another type of a similar instrument (Fig. 2b) the pendulum rotating about its axis is replaced by elastic reeds with weights fixed to their free ends. In this case the reeds can be made to oscillate either by electrical or pneumatic means (similar to a reed of an accordion).

Frequency transducers of the pendulum type can be used not only for measuring nonelectrical quantities, but also for measuring in a digital form purely electrical quantities. As an example we can cite the digital electrostatic voltmeter (Fig. 2c) suggested by the author in conjunction with P. T. Lek and G. A. Kondrashkova. If the measuring element of this voltmeter is made with a negligibly small mechanical stiffness in such a manner that when it is deflected to either side from its natural position it produces a restoring (return) torque $W = c \cdot U^2$ (which in the case of electrostatic mechanisms is provided with the simplest shape of plates), the frequency of natural oscillations of such a system will be equal to:

$$f = \frac{1}{2\pi}\sqrt{\frac{W}{J}} = \frac{1}{2\pi}\sqrt{\frac{cU^2}{J}} = \frac{1}{2\pi}\sqrt{\frac{c}{J}}\,U, \quad (4)$$

where c is a design constant; J is the moment of inertia of the moving part; and U is the effective value of the measured voltage.

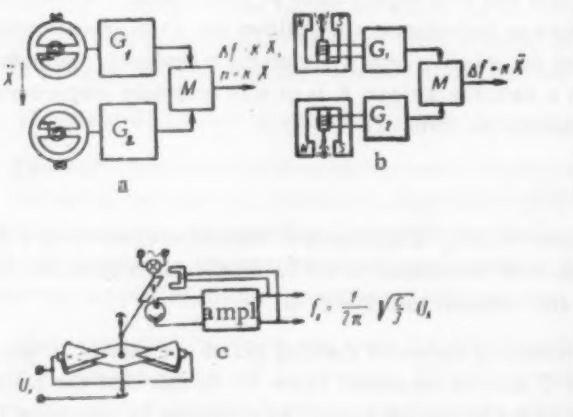


Fig. 2 .

The advantages of voltmeters of this system consist of a high and constant sensitivity, since the design constants J and c only depend on the geometrical dimensions of the instrument's elements and do not depend on the properties of these elements (friction, stiffness, etc.), as well as of a direct digital readout in measuring both dc and ac voltages right up to high radio frequencies.

3. Transducers with a variable time delay, which belong to the third group, are represented by an electrostatic voltmeter with a floating ball. Two flat electrodes connected to the measured voltage are immersed in a viscous nonconducting liquid (Fig. 3a). The ball which floats in liquid is attracted to one electrode, acquires a charge of the same sign as the electrode, is repelled from it and attracted by the opposite electrode. On touching the other electrode it loses its charge, acquires another of the opposite sign, produces a current pulse in the electrode and is repelled from it. The velocity of the ball and hence the

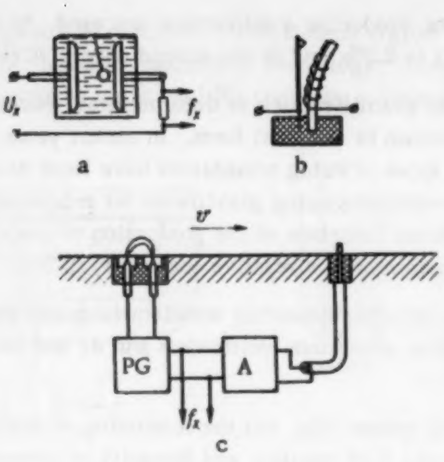


Fig. 3.

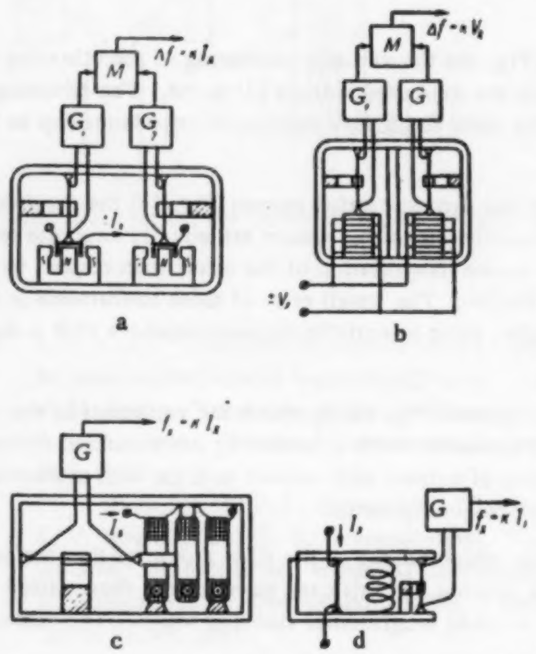


Fig. 4.

period and frequency of its oscillations are determined by the viscosity of the liquid and the applied voltage. The effect of temperature on viscosity is, according to American data, eliminated by using silicon-organic liquids.

Another example of such transducers consists of the electrolytic counter developed by the "Vibrator" plant. The gas liberated in electrolysis displaces along the glass tube a drop of an electrically conducting liquid. At the end of its travel the drop shortcircuits two contacts which switch-in a relay and the measured current is connected to another electrolytic cell, whose gas is propelled from the opposite end of the tube, returns the drop until it closes another pair of contacts. The velocity of this drop is proportional to the current. Thus, the frequency of the drop's oscillations is proportional to the value of the measured current, and the total number of oscillations to the quantity of electricity. On similar lines electroosmatic frequency transducers may be constructed.

A similar principle of operation controls instruments based on the heating if bimetallic elements which disconnect the heating circuit (Fig. 3c) and on cooling reconnect it. In this case the frequency of oscillation is proportional to the square of the current, and such instruments can therefore be used for a square -law conversion of the measured value.

In concluding the examination of time-delay transducers, mention should be made of the frequency transducers of velocity, displacement and gas flow [5]. Electrodes of a pulse generator PG (3-15 kv) are placed in an air stream (Fig. 3c). The sparks between them ionize a small volume of air (produce an ionic "marker") which is carried by the air stream to the receiving electrode which is placed at a given distance from the generator (100-200 mm). The instant the "marker" passes near the receiving electrode is registered by a sensitive amplifier A, which us used to trigger the pulse generator and produce the next ionic "marker." The pulse repetition frequency of such a transducer is directly proportional to the measured speed and inversely proportional to the distance between the receiving and transmitting electrodes, and the total number of pulses is proportional to the displacement or flow of gas. The advantages of such a frequency transducer (in addition to its exceptionally simple integration of speed) consists in its applicability for measuring both infrasonic and supersonic speed of gas flow, thus presenting a considerable advantage as compared to any other aerodynamic speed transducer.

4. Transducers with linearly distributed parameters, belonging to the fourth group, are represented by such widely known instruments as string strain gauges, dynamometers, thermometers, etc. These transducers consist of self-oscillatory devices whose frequency is determined by the mechanical natural frequency of vibrations of a taut string, in the same manner as a tuning fork sets the frequency of a tuning-fork generator. The natural frequency of a taut string is determined by the expression:

$$f=\frac{1}{2}\sqrt{\frac{F}{lm}}, \tag{5}$$

where F is the string tension; l is the length of the string, and m is its mass.

The relation between the frequency of a string transducer and the force applied to it or its length is nonlinear. In order to linearize it only small portions of this nonlinear relationship are used, or a differential system consisting

of two string generators with opposite signs in their frequency variations, producing a difference, are used. In the first instance the nonlinearity for a frequency deviation of 5% amounts to 2.5%, and in the second case to 0.12%.

String transducers can be used not only for measuring mechanical quantities such as deformations, forces, pressures, etc. [6],but also for measuring temperature [7] with its representation in a digital form. In recent years owing to the use of digital electronic machines several new highly accurate types of string transducers have been developed. Thus, the All-Union Scientific Research Institute of Geophysics has developed a string gravimeter for prospecting, with a sensitivity of $10^{-7}$-$10^{-8}$ m/sec$^2$ [8]. Reports have appeared in American literature of the production of micromanometers with a relative sensitivity of $2 \cdot 10^{-7}$ and rocket string accelerometers with a relative sensitivity of $5 \cdot 10^{-6}$ [9].

In 1959-60, the author suggested the use of string transducers not only for measuring nonelectric quantities, but also for the production of digital electrical measuring instruments such as ammeters, voltmeters and dc and ac electricity meters.

In digital ammeters and electricity meters of the magnetic string system (Fig. 4a) the tensioning of the vibrating string is provided by a sliding moving coil mechanism. In order to obtain high stability and linearity of conversion, two differentially connected generators are used. A model of such an instrument made in the LPI (leningrad Polytechnical Institute) had a limit of 10 ma and an error of the order of the fourth decimal place. The great advantage of this instrument consists in the possibility of prolonged integration with respect to time of dc values represented by several milliamperes.

In the digital voltmeter of a piezoelectric string system (Fig. 4b) the variable tensioning of the vibrating string is provided by the inverse effect of a piezoelectric pile to which the measured voltage $\pm U$ is fed. The advantages of such voltmeters and integrators consists in the absence of moving parts and a very high input impedance (up to $10^{12}$ ohm for direct voltages and up to $10^{10}$ ohm at 50 cps).

In digital ammeters, wattmeters and electricity meters of the dynamic string system (Fig. 4c) the tensioning of the string is varied by an electrodynamic mechanism; hence, instruments of this system are equally accurate for direct and alternating currents and may be used as comparators. The square-law relation of the effort with respect to the current provides a linear transformation function for the whole device. The small error of these instruments is due to the very small displacements of their moving part, which makes them essentially ampere-balances with a digital readout.

Finally, there are digital instruments of the thermostring system (Fig. 4d) in which the variations in the tensioning of the string are provided by the extension of a torsion suspension which is heated by the measured current $I_x$. Such instruments provide a linear digital conversion or integration of current with respect to time with moderate accuracy (of the order of the third decimal place) over a very wide frequency range.

5. Transducers with volumetrically distributed parameters, which belong to the fifth group, utilize the propagation of mechanical or electromagnetic oscillations in a given volume. In this case waves of the most varied configurations can be used; however, the simplest method consists in using longitudinal standing waves. The resonator can be hollow or filled with gas, liquid or a solid body.

A typical case when solid resonators are used consists of quartz or magnetostriction generators. For instance, in order to measure the thickness X of an ice covering it is sufficient to place the crystal of a quartz generator on the surface subject to icing (Fig. 5a). The icing will increase the effective crystal thickness and the frequency $f_x$ of the generated oscillations will accordingly decrease. The principle of operation of these instruments approaches very closely to that of modern ultrasonic thickness meters and fault detectors.

When a hollow resonator is filled with liquid and operates with a longitudinal standing wave, the generated oscilations are propagated to the surface of the liquid and then reflected back. Hence, such a resonator can be used as a tuned circuit which determines the generator frequency. The period of oscillations of such a generator is directly proportional to the length of the resonator and inversely proportional to the speed of wave propagation in the medium. This principle can be used for constructing digital transducers for level meters, and for a given level, gauges for measuring the density, composition and temperature of the liquid.

If the hollow resonator is filled with gas instead of liquid, the mathematical relationship remain the same, with the exception that the speed of sound propagation in gas is affected by temperature to a far greater extent than in liquids. Therefore a gas digital thermometer (Fig. 5c) is more sensitive than a liquid thermometer and is already

being used in practice. Several such digital thermometers have been produced at the D. I. Mendeleev All-Union Scientific Research Institute of Metrology. They are employed for accurate determination of reference points in the temperature scale used for checking purposes.

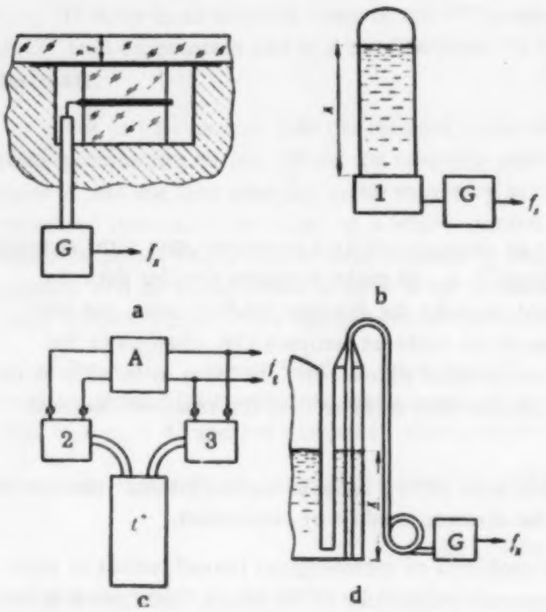


Fig. 5. 1 = exciter; 2 = microphone; 3 = telephone.

The speed of sound propagation is very sensitive to the composition of the gas. Thus, for hydrogen it amounts to 1260 m/sec, for nitrogen to 337.5 m/sec, and for carbon dioxide to 258.3 m/sec. These properties of gases can be utilized for making digital gas analyzers using a differential circuit in order to eliminate the temperature effect.

Finally, by using coaxial resonators for electromagnetic vibrations and filling them partly with electrically conducting liquid (Fig. 5e) we obtain a digital level meter whose readings are not affected by temperature, or the condition of the liquid (inclined surface, impurities, or even waves or boiling).

Conclusions. The production of frequency transducers of digital instruments for measuring various physical quantities is one of the most promising trends of development of modern electrical measuring techniques. The above-mentioned 24 types of frequency transducers for digital measuring instruments do not in any way exhaust all the possible varieties; however, they alone cover the greater part of measurable physical quantities.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

# EXPERIMENTAL INVESTIGATION TECHNIQUE OF AN ELECTRONIC CONVERTER OF VOLTAGES INTO TIME INTERVALS

M. A. Zemel'man

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pp. 22-27, April, 1961

In developing measuring instruments with a digital readout or an analogue-digital converter, one aims at making the error of measurement or conversion to the error of discrete readings, i. e., to make the error smaller than the smallest decimal unit. Moreover, it is necessary to take into account not only the discrete reading error, but also other factors, such as nonlinearity of the conversion scale, variations of the ambient temperature, changes in the supply voltage, zero drift, variations in the internal resistance of the measured source, etc. In order to be able to neglect the errors due to all these factors, these errors must be made considerably smaller than the smallest decimal unit.

In the above instruments one should also take into consideration such effects as the so-called internal conversion noise or random errors due to causes which are not connected with the discrete method of conversion.

Determining all the above errors is one of the most important problems of metrological investigations of analogue to digital converters and digital measuring instruments. An important parameter of the above instruments is the delay in stabilizing the reading, i. e., the duration of transient processes. This time must be known in order to determine correctly the frequency of sampling or the conversion cycle of the instrument.

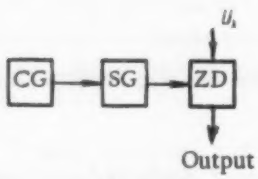


Fig. 1.

This article deals with the experimental research technique and certain peculiarities in the operation of analogue to digital converters of one specific type, the converters based on the comparison of the converted (or measured) voltage with a linearly varying reference voltage. The properties of such instruments depend mainly on the characteristics of the converters of voltages into time intervals (VTIC), which are always included in analogue to digital converters based on a voltage ramp.

The normal block schematic of such a converter is shown in Fig. 1.

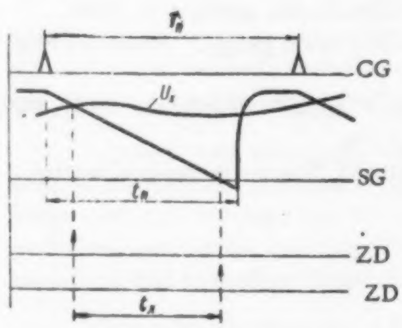


Fig. 2.

Here CG is the cadence generator which sets the conversion frequency, SG is the generator of the sawtooth reference voltage $U_n$, and ZD is the zero detector. Figure 2 shows the time diagram of the converter operation, whose zero detector consists of two identical circuits, one of which operates at the instant the measured voltage $U_x$ equals the reference voltage $U_n$ ($ZD_1$), and the other at the instant the reference voltage $U_n$ passes through zero ($ZD_2$). Two pulses appear at the output of the zero detector, with the interval $t_x$ between them being proportional to the measured voltage $U_x$.

Metrological investigations of an electronic VTI converter are difficult owing to the limited accuracy of time interval meters (TIM) required for measuring the output time intervals in a VTI converter. For instance, if it is required to measure a voltage with an error of 0.1% an electron three-digit TIM counter is used. In this arrangement the discrete measurement error amounts to 0.1%, and the measurement of the converter output time intervals with greater precision which is required for certain systematic conversion errors is, it would appear, impossible.

However, from our point of view it is possible by using a certain technique to investigate the behavior of the VTI converters in the greater part of actual operating conditions by means of an electronic TIM counter with an error considerably smaller than the discrete counting error of a TI meter.

The method of measuring time intervals by means of electronic counters consists of making pulse A, which determines the beginning of the measuring interval, to close the switch which connects to the electronic counter pulses of the reference frequency $f_0$, and to make pulse B, which determines the end of the interval, to disconnect the switch, thus stopping the supply of these pulses to the counter.

If there is no internal noise in the VTI converter the time interval between pulses A and B for a constant value of $U_x$ will be constant and will not fluctuate. In the presence of internal noise in the VTI counter, interval $t_x$ will fluctuate.

Let us first assume that the internal noise does not exist and $t_x = \text{const}$. The measured interval $t_x$ (Fig. 3) contains $n_x$ counting pulses. Since the counting pulses are not synchronized with pulses A and B, interval $\Delta t_1$ between pulse A and the first counting pulse may vary at random for various counting cycles and a uniform distribution. If the measured interval is not equal to a whole number of periods $T_0$ ($t_x = n_x T_0 + \Delta t$, where $0 < \Delta t < T_0$), the number of counting pulses which will fit into interval $t_x$ may be equal to $n_1 = n_x$ or $n_2 = n_x + 1$. Moreover, the reading of the counter will be equal either to $n_1$ or to $n_2$, and the error of a single reading must be assumed to be equal to the discrete counting error. The random measuring errors of counter TIM may be evaluated in the following manner*.

Interval $T_x$ is expressed by the number $N_x = n_x + \Delta n$, where $n_x$ is the number of integers and $0 < \Delta n < 1$. The reading of the TIM counter will then be equal to $N_r = n_x$ or $N_r = n_x + 1$. The number $\Delta n$ is equal to the probability that $N_r = n_x + 1$, and the number $(1 - \Delta n)$ is equal to the probability that $N_r = n_x$.

The expectation value of the readings will be:

$$MN_r = \Delta n\,(n_x + 1) + (1 - \Delta n)\,n_x = n_x + \Delta n,$$

and the dispersion of the readings equal to:

$$DN_r = \Delta n\,(n_x + 1 - MN_r)^2 + (1 - \Delta n)(n_x - MN_r)^2 = \Delta n\,(1 - \Delta n)^2 + (1 - \Delta n)(-\Delta n)^2 = \Delta n\,(1 - \Delta n).$$

Depending on the value of $\Delta n$ the dispersion lies somewhere in the range of $0 < DN_r < 0.25$, with its maximum value occuring for $\Delta n = 0.5$. The dispersion is equal to zero for $\Delta n = 0$, i. e., for $N_x = n_x$ or $t_x = n_x T_0$.

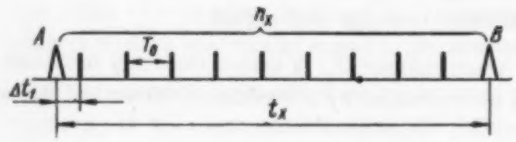

Fig. 3.

When the dispersion of the counter readings equals zero it means that for $t_x = n_x T_0$ the counter reading is stable. It is obvious thet the reading of the counter thus obtained $N_r = N_x$ corresponds to the measured interval $t_x$ which is independent of the discrete measurement error of the counter.

It should be noted that in deriving the expression for the dispersion an assumption was made that no synchronization existed between the voltage ramp and the reference frequency counting pulses. Hence, interval $\Delta t_1$ (Fig. 3) is a random uniformly distributed quantity. Since no other assumptions were made, it can be expected that the dispersion of the TI meter readings in testing the VTI converter, which has a low internal noise, will satisfactorily meet the above expression. This has been confirmed experimentally. Thus, for certain values of $U_x$, which meet the condition $T_x = n_x T_0$, the readings of the TI meter become stable, nonfluctuating. The error in the readings of the TI meter then become independent of the discrete reading error of the counter. In practice there will only remain the other error componenet of the TI meter readings due to the instability of the frequency $f_0$ of the counting pulse generator. Such generators are usually crystal controlled and the error of their frequency is incomparably smaller than the actual TI meter discrete reading error, which can thus be neglected in testing the VTI converters. Hence, the stable readings of the TI meters can be taken for the actual value of interval $t_x$ with an error considerably smaller than the discrete reading error.

On the basis of the above reasoning it is possible to suggest the following technique for testing the accuracy of the VTI converters. A definite stable reading of the TI meter is obtained by smoothly varying voltage $U_x$ whose value thus obtained is then measured on a dc potentiometer. These measurements are made under the various condi-

* The approacn made in this article to the evaluation of random errors in the readings of the TI meter was suggested in a work conducted in the MAI (Moscow Aviation Institute) under the guidance of E. I. Gitis.

tions whose effect on the operation of the VIT converter it is required to investigate. The readings of the MIT counter are set to the same value for all the different conditions. The difference between the appropriate values of voltage $U_x$ will then determine the effect under investigation. For this purpose voltage $U_x$ must be sufficiently stable. The above errors of the VTI converter are calculated from the formulas

$$\delta = \frac{U_n - U_a}{U_{n\,max}} \cdot 100\%,$$

where $U_n$ is the nominal converted voltage, which corresponds to the set time interval $t_x$:

$$U_n = t_x \frac{U_{n\,max}}{t_{max}};$$

$U_{n\,max}$ is the maximum nominal converted voltage; $t_{max}$ is the nominal time interval corresponding to voltage $U_{n\,max}$; $U_a$ is the actual value of the converted voltage corresponding to the set time interval $t_x$.

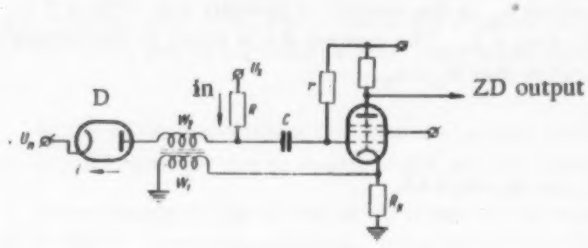

Fig. 4.

All the above holds if there are no internal noises in the VTI converter. In fact, these noises always exist and make time interval $t_x$ fluctuate. Moreover, the counter reading dispersion will exceed the value calculated from the above expression. For each conversion cycle, intervals $t_x$ will have random values grouped around a mean value $t_{xm}$. Hence, even if $t_{x\,m}$ is equal to a whole number of reference frequency periods, the counter readings will fluctuate.

However, if the internal noise of the VTI converter is small, the dispersion of the counter readings for $t_{x\,m} = n_x T_0$ will be considerably smaller than in the case of $t_{x\,m} \neq n_x T_0$. In practice this amounts to the fact that for $t_{x\,m} = n_x T_0 + 0.5\,T_0$ i. e. for $\Delta n = 0.5$ the counter readings will assume various values from which it will be impossible to detect visually the one which occurs most often; but although for $t_{x\,m} = n_x T_0$ the counter readings will also assume different values, one of them will noticeably preponderant. It follows from the above that for $t_{x\,m} = n_x T_0$ the readings of the counter will be more stable. With a small internal noise it will be in practice possible to set a value for $U_x$ for which the readings of the counter will be stable, i. e., a definite reading will last for a sufficiently long period and only seldom other readings will appear.

The impossibility of obtaining stable readings of the counter when voltage $U_x$ is varied smoothly indicates the existence of a large internal noise in the converter. This noise can be evaluated by a method at the end of this article.

In the above converters the internal noise must be small, and therefore it will be possible by means of the suggested technique to determine any systematic errors in the converters, for instance, the "calibration error," i. e. the degree of nonlinearity of the converter scale, the effect of supply voltage variations on the converter readings, etc. Moreover, the stability of the converter readings with time can also be determined.

We tested a converter by means of the above technique with a TI meter which had a three-figure display, i. e., a discrete reading error of 0.1%. The consistency of the results thus obtained shows that the random measurement errors did not exceed 0.01-0.02%. The systematic errors due to those of the dc potentiometer and the frequency of the reference generator were also negligibly small.

Important technical characteristics of the VTI converter consist in its input impedence and the transient period in obtaining its readings. These characteristics are determined in practice by the properties of the converter's zero detector. In order to understand the causes affecting the above characteristic, it is necessary to examine the operation of the zero detector in greater detail than has been done in [1, 2]. As a concrete example let us take the widely used diode zero detector with a positive transformer feedback. (Fig. 4).

At the beginning of the measuring cycle (Fig. 2) as long as $U_x < U_n$, diode D is blocked, but the output pentode of the zero detector is conducting. Capacitor C is charged up to voltage $U_x$ along the circuit consisting of R-C the space between the grid and cathode of the tube. The voltage at the anode of the diode (with respect to "ground," i. e. the zero level) is equal to the voltage at the capacitor C. The diode must become conducting at the instant

when $U_n = U_x$. For this purpose capacitor C must have time to charge to voltage $U_x$ before the measuring cycle begins. At the instant the diode becomes conducting it closes the positive feedback circuit, the pentode is rapidly blocked and a positive pulse appears at the output of the zero detector. When the diode conducting the pulses of the input current $i_{in}$ and current $\underline{i}$, which are provided by the sawtooth generator SG, begin to flow and capacitor C discharges slightly. After the lapse of a time $t_n$ at the end of the sawtooth voltage ramp (Fig. 2) the diode is again blocked, current $\underline{i}$ stops flowing and capacitor C begins to charge up to voltage $U_x$ during the open circuit condition. If capacitor C has not sufficient time to charge up to voltage $U_x$ during the open circuit condition, the relation of the output time intervals to voltage $U_x$, i. e. the conversion scale, becomes nonlinear. The smaller the conversion cycle $T_n$ (Fig. 2), the quicker must capacitor C be charged. Hence, the higher the conversion frequency, the smaller must be the time constant of capacitor C charging circuit, i. e., the smaller must be the resistance R which includes that of the $U_x$ voltage source.

On the other hand, a reduction of resistance R raises the currents $i_{in}$ and $\underline{i}$. Current $i_{in}$ directly loads the source of the measured voltage and must therefore be small. Current $\underline{i}$ loads the source of the reference sawtooth voltage and may cause for a certain output impedance of this source nonlinearity in the sawtooth voltage, which cannot be tolerated, especially in multichannel converters. In selecting the value of resistance R a comprise must be reached for each particular case.

The peculiarities of the operation of the zero detector are such that it cannot be characterized by the simple conception of an "input impedance," as is done for instruments whose input circuit is a linear passive two-terminal network.

It is advisable to evaluate the peroperties of the MTI converter input circuit by two characteristics, namely input current $i_{in}$, and the relationship of the converter readings to the internal impedance of the source.

Figure 5 shows an oscillogram (time pips at every 100μ sec) of the converter input current for a particular case, which provides an idea of the quantitative characteristic of the input current pulses.

It is interesting to note that if the single polarity current $i_{in}$ pulses in the converter input circuit are instrument which measures mean voltages (for instance, on a moving coil instrument), and is connected in parallel with the converter, its readings may differ from those of a counter connected to the converter output. The mean voltage measured at the terminals of the instrument and the converter will not equal the source emf, since the mean value of current $i_{in}$, which flows through the internal resistance of the source, is not equal to zero. The moving coil instrument (this also refers to a dc potentiometer) will measure the mean voltage at the terminals, but the reading of the converter counter will be practically equal to the source emf.

In examining the effect of the internal resistance of the voltage $U_x$ source on the reading of the converter it is necessary to take into consideration the following facts. The internal resistance $R_{in}$ of the source $U_x$ may be considered as part of resistance R. For large values of $R_{in}$ charging of the capacitor C may not be completed before the beginning of the next cycle, thus leading to a reduction in the output time interval as compared with that obtained for a small $R_{in}$.

Moreover, an important part may also be played by another circumstance.

It is known from [1] that the zero detector will operate at the instant when the gain of the open-circuited feedback circuit of the zero detector becomes equal to unity. For the circuit shown in Fig. 4 the gain of the open-circuited feedback (neglecting the output impedance of generator SG) is equal to:

$$K = k_1 \frac{w_2}{w_1} \cdot \frac{R_e}{R_e + R_d},$$

where $k_1$ is the gain of the tube stage, which is equal to the ratio of the voltage across resistor $R_k$ to the voltage on the control grid of the tube; $w_1$ and $w_2$ are the number of turns of the thermometer windings; $R_d$ is the diode resistance, and

$$R_e = \frac{(R + R_{in}) R_{gk}}{R + R_{in} + R_{gk}},$$

where $R_{gk}$ is the grid to cathode resistance of the tube.

The expression for $R_e$ holds if the effect of the capacitance C reactance on the alternating component of the current is neglected, which is permissible in practice. It will be seen from the expression for K that the larger the value of $R_e$, i. e. that of $R_{in}$ (with the remaining conditions unchanged), the sooner will K become equal to unity. Thus, if the converter is calibrated for a value of $R_{in0}$, then for a larger vlaue of $R_{in}$ the output time interval will be larger than that whoch would have been obtained for $R_{in0}$. This phenomenon and the complete charging of the capacitor for a large $R_{in}$ have opposite effects on the conversion error. Hence, under certain conditions the rising of the value of $R_{in}$ may produce either a rise or a fall in the converter readings.

When determining the causes affecting the transient period in the converter readings it is necessary to take into consideration the following circumstances.

It has already been mentioned that for correct operation of the converter it is necessary for the voltage across capacitor C to be at the instant of the zero detector operation equal to $U_x$. If the value of $U_x$ suddenly changes the voltage across the capacitpr cannot follow it instantaneously.

Capacitor C gradually charges up to the new value of $U_x$ over the circuit consisting of R-C, the space between the grid and cathode of the conducting tube. However, the charging time of the capacitor C does not only depend on the time constant of this circuit. The charging of capacitor C only takes place during that part of the conversion cycle when diode D is blocked. During that part of the cycle when diode D is conducting, the capacitor discharges through the diode. In a steady-state condition this discharge is very small; however, the discharging of capacitor C during a certain part of each cycle may considerably affect tne time required for the voltage across the capacitor to follow variations in $U_x$. This effect becomes, if the remaining conditions are unchanged, more pronounced at higher frequencies, when the diode conducts during a larger relative part of the conversion cycle than at lower frequencies (for the same duration $t_n$ of the reference voltage).

As the result of this phenomenon a sudden rise in $U_x$ will be followed by a gradual increase of the converter readings up to a steady-state value.

In some of the converter circuits the reference voltage $U_n$ is fed from the SG generator to the zero detector through dividing capacitors $C_d$. In such cases the level of the reference voltage fed to the zero detectoe is determined with respect to ground by an additional potential divider connected on the other side of capacitor $C_d$. The diode cathode is then connected to the midpoint of the divider.

It has already been mentioned that for a certain part of the conversion cycle current $\underline{i}$ flows in the diode circuit of the zero detector (Fig. 4). This current, which depends on voltage $U_x$ provides an additional voltage drop across the lower arm of the potential divider, thus causing a difference in the reference voltage level fed to the zero detector*.

The circuit must be arranged in such a manner that variations in the value of $U_x$ should produce equal changes due to current $\underline{i}$ in the levels of the reference voltages fed to both the zero detectors. It is known that in a circuit with two zero detectors small variations in the reference voltage level do not affect the operation of the converter.

However, it should be remembered that the latter assertion only holds when the level variation process has been completed. If the reference voltage level varies during the conversion cycle, then obviously the readings will also change. Immediately following a jump in the value of $U_x$ the variation in current $\underline{i}$ will produce a smooth change in the reference voltage level (owing to the presence of capacitors $C_d$). Hence, the operation of zero detector $ZD_1$ will correspond to a certain level and that of $ZD_2$ to another level of the reference voltage. For instance, when a sudden increase in $U_x$ produces a gradual rise in the reference voltage level, the converter readings will first exceed the steady-state value, but after decreasing gradually they will attain that value.

The two phenomenon we have analyzed, namely the variations in the charging of capacitors C and $C_d$, affect the converter readings during their transition period in a different manner. Owing to the variations in the charge of capacitor C the readings will at first be smaller than their steady-state value, whereas owing to the same effect in capacitor $C_d$ they will be larger than that value.

In many instances the transient period in the converters may have a decisive effect. This period should be considered as one of the important converter characteristics.

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*Although current $\underline{i}$ has a pulsed characteristic, it causes a steady shange in the level of the reference voltage, owing to the presence of capacitors $C_d$.

In theory the technique of measuring the transient period in converters is fairly simple. It is only necessary to measure the time which elapses between the instant of the jump in the value of voltage $U_x$ and the instant the time interval meter operates. This technique can be easily achieved if there is a device for registering with respect to time the readings of the counter. Such devices are rather complicated and are not as yet in general use. However, the transient period in the readout can be determined without such a recording device by means of an artificial technique.

Between the VTI converter and the TI meter a scaling circuit with an adjustable scaling factor is connected. An operating condition of the TI meter is established for which it registers only one (the first) pair of pulses fed to it, and retains the (single) reading thus obtained on the counter for any length of time, until the counter is restored manually. Before the testing begins the required scaling factor is set in the scaling circuit and it is blocked. When the converter is connected its pulses do not reach the input of the TI meter, since the scaling circuit is blocked. Simultaneously with a jump in the voltage $U_x$ the scaling circuit is opened. If its scaling factor is equal to $\underline{n}$, the input of the TI meter will receive the $\underline{n}$th pulse of zero detector $ZD_1$, thus measuring time interval $t_x$ for the $\underline{n}$th transformation period. By setting the values of $n=1$, $n=2$, $n=3$, etc., and repeating every time the same sudden variation of voltage $U_x$, it is possible to obtain converter readings at the 1st, 2nd, etc. conversion periods before a steady-state condition is reached. From the knowledge of the conversion frequency it is possible to determine approximately the transient period of the readout.

The evaluation of random errors in converting voltage into a digital form is of great practical interest. These errors are due to two factors, the internal noise of the converter and the lack of synchronism between the VTI output pulses and the reference frequency pulses. In the absence of any internal noise or when it is insignificant, random errors can be evaluated satisfactorily by calculating the readings' dispersion, whose values is given above for the condition of $t_x$ = const. If the internal noise produces a noticeable effect, random errors should be evaluated experimentally.

Fig. 5.

The technique of determining random errors in the voltage to time interval converter is theoretically different from the normal method of determining random errors in measuring instruments. For each value of voltage $U_x$ a sufficiently large number of the counter readings are taken. If the readings are observed visually the sawtooth should be operated for one voltage ramp at a time, or the counter set in an operating condition which would provide readings at sufficiently widely spaced intervals, for instance, once in every 3-5 sec.

By processing the measurement results it is possible to determine for each value of $U_x$ the dispersion in readings which characterizes the random errors. In the case of small internal noise in the VTI converter the dispersion will vary in measuring $U_x$ within the limits of a quarter of a unit of the smallest order read by the instrument (see above).

The internal noise of the VTI converter can be determined in the following manner. The values of voltage $U_x$ are set at small intervals, for instance, corresponding to 0.1-0.2 of a unit of the smallest order read on the counter. The total range of variations in $U_x$ should amount to not less than 1.5 units of the lowest order on the instrument. For each setting of $U_x$ repeated readings are taken and for each of its values dispersions in the readings are calculated. If the effect of internal noise is not predominant the values of dispersion corresponding to various values $U_x$ will vary. The curve showing the relation between dispersions and $U_x$ will have a minimum at the value of $U_x$ corresponding to the condition $t_{x\,m} = n_x T_0$. This minimum value of dispersion is the approximate measure of the internal noise of an VTI converter.

The number of readings registered in these experiments or the accuracy in evaluating the internal noise dispersion is determined according to certain rules on the basis of given values of the confidence interval and the confidence probability [3].

The above technique of an experimental investigation of voltage to time interval converters was used in developing a converter in the range of 1 to 10 v with a time interval of 1 μ sec and a referred error not exceeding 0.1%.

In the course of this work, as has already been mentioned, it was established that the error in using a TI meter with a three-figure readout for determining various systematic errors and the instability with time of converter did not exceed 0.01-0.02%. The square root of the internal noise dispersion amounted in these measurements to about 0.02%.

Investigations have also shown that for the operation of the converter with the above characteristics in the frequency range of 40-320 cps, resistance R (Fig. 4) must have a value in the range of 200-50 kiloohm for a scale nonlinearity of 0.02-0.05%. The readout transition period due to the slow charging of capacitor C amounted to two conversion cycles (50 $\mu$ sec) at a frequency of 40 cps and to about four conversion cycles (120 $\mu$ sec) at a frequency of 320 cps.

S. V. Rypalev participated in this work.

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2. Millman and Taub, Pulse and Digital Circuits, 1956.
3. E. S. Vent-tsel', Theory of Probabilities [in Russian](Fizmatgiz, Moscow, 1958).

# TRANSISTORIZED STABILIZERS FOR FEEDING TESTING INSTALLATIONS

Translated from Izmeritel'naya Tekhnika, No. 4,
p. 27, April, 1961

Note to the article by S. D. Dodik and M. I. Levin.

In the schematic of the stabilizer (Measurement Techniques, No. 3, 1961, bottom of page 29) the collector of transistor $T_1$ has been demoted as the emitter, and vice versa. The choke L should in fact be connected to the collector of $T_1$, and the emitter of $T_1$ should be connected to the negative side of the output voltage.

# HIGH-SPEED ELECTROMECHANICAL DIGITAL VOLTMETER

V. M. Shlyandin

Translated from Izmeritel'naya Tekhnika, No. 4,
pp. 27-29, April, 1961

The known electromechanical voltmeters with a digital display used for measuring direct voltages are based on a compensation circuit whose balancing is achieved during measurements by the control unit which switches in consecutively (samples) the resistors in the circuit. This is done by means of commutating elements consisting of motors, step-by-step switches or relay circuits, programmed by means of a step-by-step switch. In the balancing process the difference $U_x$-$U_k$ between the measured and compensating voltages is decreased in consecutive steps to a predetermined procedure, until it attains a value smaller than the minimum calibration of the instrument.

The characteristic of the voltmeter here described consists in the absence of the consecutive comparison (sampling) of the measured voltage, with the voltage drop across individual resistors in the compensation circuit, i. e., a complete elimination of a long balancing process characteristic of normal instruments. Each voltmeter decade registers approximately the absolute value of the $U_x$ voltage applied to it, compares it with the corresponding value of the reference voltage, and obtains the difference $U_x$-$U_k$. The absolute value of this difference is approximately registered by the next decade and compared with the corresponding value of the reference voltage of that decade, etc. The main advantage of the above voltmeter consists in its high-speed operation and the easy requirements with respect to the adjustment of the decade comparing elements.

The voltmeter should consist of a source of reference voltages and of decades which are identical in construction and whose number is equal to the number of readout figures. Figure 1 shows part of the first decade in the initial state before commencing measurement. At this instant the zero readout lamp $LO_1$ is alight. When the starting push-button SP is operated the measured voltage $U_x$ is fed to the input of the cathode follower CF, and then simultaneously to all the relaxation relays $P0_1, P1_1 \ldots . P10_1$ (of the type of driven transistor multivibrators with one stable position). Relay $P0_1$ is tuned to operate at $U_x$ which is equal to or larger than the voltage corresponding to the smallest readout figure (minimum calibration) of the voltmeter. It operates and closes contacts $1KP0_1$ and $2KP0_1$ locking itself across the last contact. Relays $P1_1 \ldots P10_1$ are tuned to operate for the values of $U_x$ equal to 10, 20, . . . 100 v, respectively (for the voltmeter top measuring limit of 100 v), with a negative tolerance whose absolute value, as it will be shown later, is not critical.

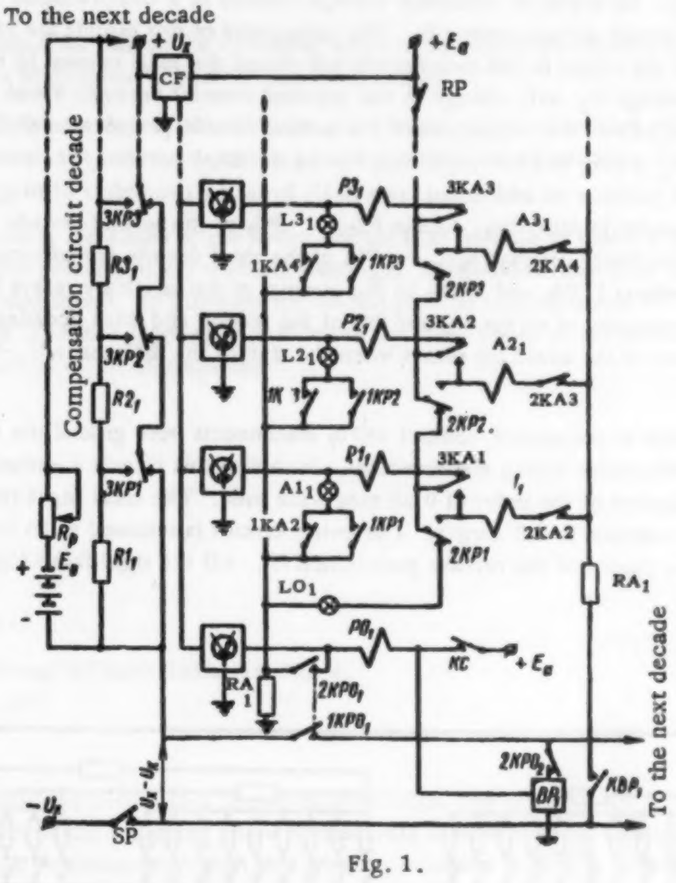


Fig. 1.

If $U_x < 10$ v, none of the relays P (with the exception of $P0_1$) will operate, and the voltage $U_x$ will be fed to the next decade. If $U_x > 10$ v, all the P relays whose operating level is below $U_x$ will operate simultaneously. However, they will immediately deenergize with the exception of the highest figure relay (and relay $P0_1$), since each higher figure relay disconnects by its contacts (2KP1, 2KP2 . . . . .) the supply to the relays of lower figures. If $U_x >$ 100 v relay $P10_1$ will operate and connect the signal lamp inscribed "$U_x > 100$ v." Let us assume that $U_x = 32.5$ v, and that relay $P3_1$ has operated. It locks itself over contact 1KP3, and connects $U_x$ by means of contact 3KP3 for comparison with the 30 v reference voltages which is obtained from a resistance decade $R1_1, \ldots R10_1$ (it is shown in a simplified manner on the drawing) of the compensation circuit. Simultaneously lamp $LO_1$ of the display device is extinguished and lamp $L3_1$ lights, and the difference $U_x - U_k = 2.5$ v is fed to the next decade which works in a similar manner.

In order to relax the requirements for the stability of the relaxation way level of operation, additional relays A1, ...A10 have been connected to the decade. If a main relay P (with a negative tolerance) operates at $U_x$ which is smaller than the nominal level for this step, for instance, at $U_x = 28.5$ v in the above example, the negative difference $U_x - U_k$ will operate auxiliary relay BP, whose operating level should be an order below the minimum voltmeter calibration so as to provide the required accuracy. Thus relay locks itself on operation, and through its KBP

contact connects the negative polarity lead to the additional relay windings. It will be seen from the circuit that if relay $P3_1$ operated incorrectly, its contact 2KP3 is moved to the upper position, connecting the anode supply to the winding of relay $A3_1$ and simultaneously disconnecting the supply from the windings of the lower figure additional relays ($A2_1$ and $A1_1$). Thus, in this case only relay $A3_1$ will operate, lock itself through its contact 3KA3, disconnecting the current at the same time from relay $P3_1$, disconnect by means of contact 2KA3 the circuit of relay $A2_1$ winding in order to prevent the possibility of its operation, and through its contact 1KA3 prepare the operation of relay $P2_1$ (this is necessary for a more reliable operation). When relay $P3_1$ releases, its contact 2KP3 is moved to the lower position, operating relay $P2_1$. Thus, the difference $U_x$-$U_k$ = 28.5-20 = 8.5 v will again become positive and will be fed to the next decade.

The schematic of the described three-figure digital voltmeter for measuring direct voltages in the range of 0-100 v is shown in Fig. 2. Its source of reference voltage consists of a compensation circuit with a varying operating current fed from a stabilized voltage source $E_0$. The resistances of this circuit are chosen in such a manner that when the contacts of one of the relays in the first decade are closed the total current in the circuit and hence the corresponding compensating voltage $U_k$ will change to the required amount between 0 and 100% of the full scale in steps to 10%. The switching-in of any of the resistances of the second decade provides an additional, lower by one order of magnitude, increase in $U_k$ owing to a corresponding rise in the total current. The switching in of any of the resistors in the third decade will produce an additional, rise in U, lower by two orders of magnitude. Relays $P0_2$ and $P0_3$ are adjusted in a similar manner to relay $P0_1$. Relays $P1_2$, . . . $P9_2$ of the second decade are adjusted to operating voltages of 1, 2, . . . .9 v, respectively. Relays $p_13$, . . . $P9_3$ of the third decade are adjusted to operating voltages of 0.1, . . .0.9 v,respectively. Contacts $2KP0_2$ and $2KP0_3$ in the circuits of the auxiliary relays $BP_1$ and $BP_2$ are disconnected one after the other by the operation of relays $P0_2$ and $P0_3$ of the second and third decades respectively in order to prevent possible false operations of the auxiliary relays when the sign of the difference $U_x$-$U_k$ changes during the measuring process.

When the second decade is connected, contact $3KP0_2$ disconnects from ground the first decade in order to raise the input resistance of the voltmeter during measurement. In testing this circuit a cathode follower and relay $BP_3$ with a total equivalent resistance of the order of 0.25 meg were used. The total input resistance of the voltmeter at the time of measurement amounted to 2.5 meg/v. The entire circuit is returned to its initial condition by disconnecting its anode supplies by means of the release push-button RP. All the significant figures in the display are then replaced by zeros.

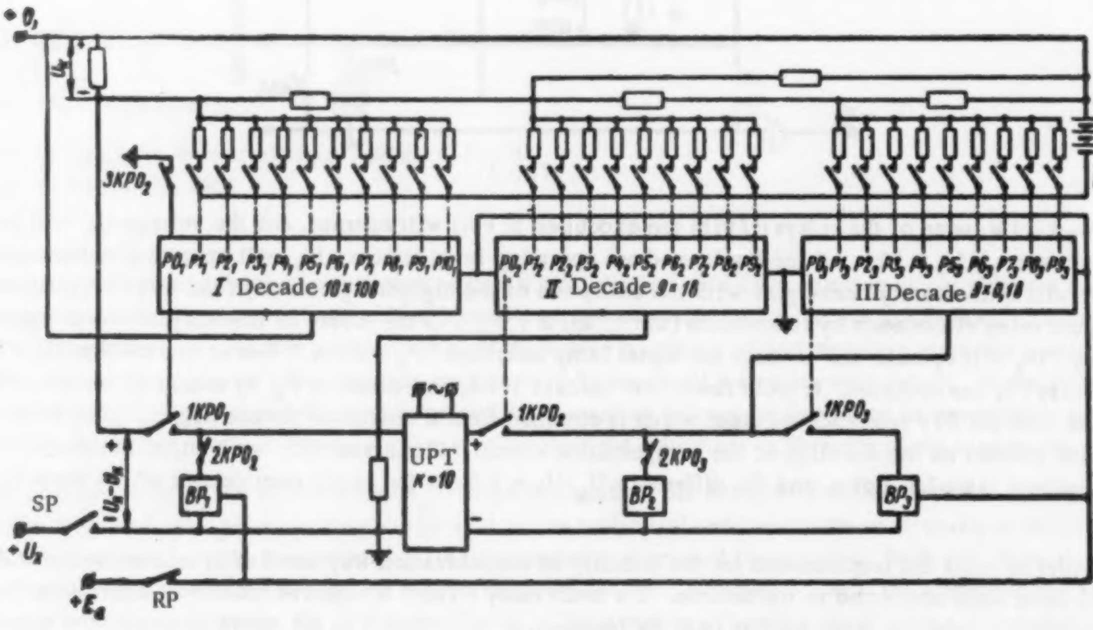


Fig. 2 .

Since all the voltmeter decades are theoretically the same, the maximum time for one measurement is determined by the number of readout digits multiplied by the total operating time of relays P, BP and A on one decade. On the basis of the worst possible case (incorrect operation of the relation relay at the beginning of measurements when the value of $U_x$ is near the voltage of one of the compensation circuit steps) the operation time of the above relays in one decade can be determined from the formula

$$t_{dec} = 2t_{op}P + t_{rl}P + t_{op}BP + t_{op}A.$$

If we assume that on an average for modern dc miniature relays each of the time intervals of this sum does not exceed 20 msec, the total operating time per voltmeter figure, which is easily attainable in practice, will amount to 0.1 sec.

Conclusions. A method for raising the operating speed of dc digital voltmeters using contact elements is suggested and a schematic for a high-speed digital voltmeter supplied.

The peculiarities of the above instrument consist of combining the relaxation relays (dc amplitude analyzers) with the compensating part of the voltmeter and in a special circuit for eliminating the possibility of an incorrect operation of a relay.

If the required elements are added to the above circuit it is possible to make a multirange voltmeter with an automatic inducation of the polarity of the measured voltage. Difficulties may arise in adjusting the relaxation relays to low voltage operating levels. In this case the circuit may be supplemented by an additional amplifier with a gain of 10, and a negative feedback large enough to make the total effect of the zero drift and gain instability smaller than the minimum calibration of the instrument.

# PHOTOELECTRIC BRIDGE

I. G. Gutovskii

Translated from Izmeritel'naya Tekhnika, No. 4,
pp. 30-34, April, 1961

This article deals with the theory of a photoelectric bridge, one of the basic units in measuring devices which are based on the conversion of the measured value successively into modulated luminous flux and a voltage or a current. Such devices include photoelectric amplifiers and compensators [1, 2, 3], photoelectric fluxmeters [4] and a number of similar instruments. Below we have generalized the results of preceding work [1, 2, 3] and derived relationships for computing a bridge with a smaller number of simplifying assumptions and taking into account its dynamic operating condition.

The schematic of the bridge and the optical system of the two basic types, with vacuum photocells PC and with differential photovaristors PV are given in Figs. 1 and 2. The bridge serves to convert displacement of the light spot, the image of diaphragm D, into a voltage or a current. The displacement of the spot is provided by the rotation of a mirror connected to a transducer using the bridge. Often such a transducer consists of a galvanometer G. In the latter case the galvanometer, optical system and the photocell bridge from a so-called photoelectrical optical amplifier (PEOA) [1,2]. The optical system consists of an illuminator L, condensor C, objective O and an optical wedge, a prism P (Fig. 1), or a mask (Fig. 2). The photovaristors (Fig. 2) are designed as part of the bridge, the spaces between electrodes 1-3 and 2-3 form the two arms of a bridge, and electrode 3 is joined to its diagonal. Image 5 of diaphragm D shines on the parts of photovaristors which are not covered by mask 4, thus providing a variation in the resistance of the bridge according to its illumination.

Having in mind designs using two simple photocells and striving to make the theory as general as possible, we shall consider each interlectrode resistor of the differential photovaristor as a separate photoelectric resistor.

It is normally considered (compare with [2]) that the electrodes (for instance, 1 and 3 in Fig. 2) are in contact with each other through conducting strips, one of which is shaded (with a conductivity of $\sigma_{mm}$) and the other illuminated (with a greater conductivity of $\sigma_{0n}$). The strips are connected in parallel so that their total conductivity is $\sigma = \sigma_{0n} + \sigma_{mm}$ with the width of the illuminated strip in each element varying, when the light flux is redistributed, in the opposite direction to that in the other element. However, since the illuminated section can be considered as a parallel connection of two strips of equal width, one of them shaded with a conductivity of $\sigma_{om}$ and the other illuminated by a variable portion of the luminous flux and having a conductivity of $\sigma_0$, i. e., $\sigma_{0n} = \sigma_0 + \sigma_{0m}$, the full conductivity of the interelectrode space can be represented as a sum of the shaded conductivity $\sigma_m = \sigma_{mm} + \sigma_{0m}$ of the whole surface of the interelectrode space, which does not depend on the position of the light beam, or as a variable conductivity $\sigma_0$. i. e. as $\sigma = \sigma_0 + \sigma_m$. The use of $\sigma_0$ instead of $\sigma_{0n}$ makes the bridge formula more convenient for analysis.

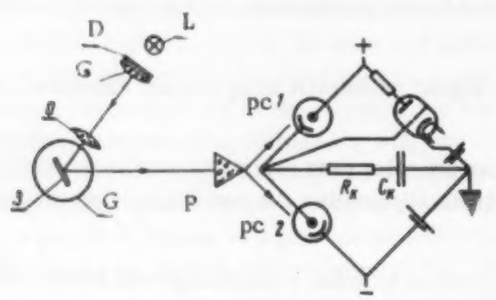

Fig. 1.

It follows from Fig. 3, which shows the relation of the photovaristors' conductivity to the luminous flux f at a constant voltage ($U_3 > U_2 > U_1$), that it is advisable to take the shaded conductivity as $\sigma_n$ which has a certain illumination $f_n$ inevitable in practice or deliberately introduced. In future we shall denote $\sigma_n$ and $\sigma_m$.

The above considerations, Ohm's law and the relation between illumination and luminous flux show that $\sigma_0$ of the photovaristors depends on the total value of the variable luminous flux independently of the width of the light spot.

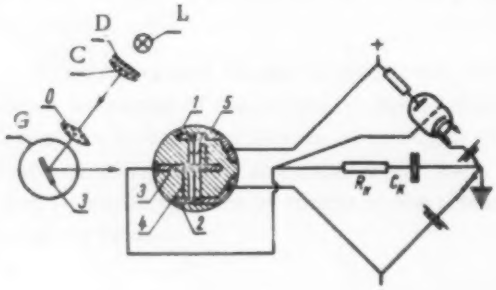

Fig. 2.

Below we examine photovaristors with characteristics approaching linearity as in the case of cadmium-sulphide photovaristors (Fig. 3) and antimonous-cesium vacuum photocells (Fig. 4).

Let us include in the bridge a stabilizing network $R_k C_k$ and the input tube of an electron amplifier. Let us consider as the output quantity the unbalanced voltage which is equal to the ac potential on the grid of the tube due to the redistribution of the luminous flux.

Basic bridge equations. For the purpose of theoretical analysis it is convenient to consider a photoelectric bridge as an emf generator whose lead consists of a diagonal circuit. In order to produce such an equivalent circuit, let us first derive the relations between the basic bridge parameters without considering the specific loading of the bridge, and limit our consideration to a series circuit of two photocells, considereing the potentials across these cells as given. Moreover, from the start we shall assume a dynamic condition, and a stable state condition as the limiting case.

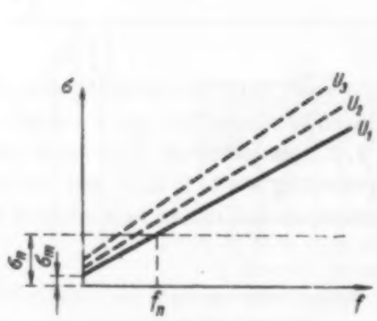
Fig. 3.

Vacuum photocell bridge. We shall neglect the self-capacity of the photocells. In the saturated position, which is recommended for use in brodges of this type [5], the working part (to the right of the inflection) of the voltampere characteristic of a photocell (Fig. 4, $f_{03} > f_{02} > f_{01}$, $f_{03} - f_{02} = f_{02} - f_{01}$; for comparison purposes the photovaristor characteristics are given for the same illuminations) is very close to a straight line.

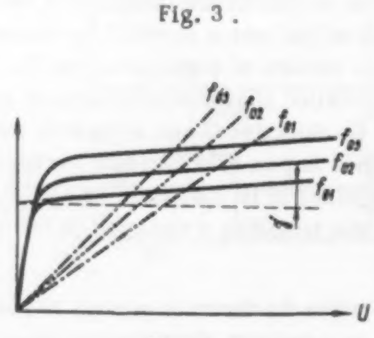
Fig. 4.

Let j = 1.2 be the photocell number, and $i_j$, $v_j$ and $f_j$ be the current, voltage and luminous flux related to it. Then having selected an optimum operating condition for $v_j = v_{j0}$ and $f_j = f_{j0}$, the operation of a photocell can be represented by an expansion into a series.

$$i_j(v_j, f_j) = i_j(v_{j0}, f_{j0}) + \frac{\partial i_j}{\partial v_j}(v_{j0}, f_{j0})(v_j - v_{j0}) + \frac{\partial i_j}{\partial f_j}(v_{j0}, f_{j0})(f_j - f_{j0}) + i_{jp}.$$

Here $i_{jp}$ is the nonlinear and by definition small part of the constant (see also Fig. 4).

$$\frac{\partial i_j}{\partial v_j}(v_{j0}, f_{j0}) = \sigma_j = \mathrm{tg}\,\gamma_j; \quad \frac{\partial i_j}{\partial f_j}(v_{j0}, f_{j0}) = \alpha_j \tag{b}$$

represents a differential (dynamic) conductance and sensitivity of a photocell in a chosen operating condition. Let us now examine the combined operation of two photocells.

If we assume that $U = \mathrm{const}$ is the bridge supply voltage, and $F = \mathrm{const}$ is the total luminous flux incident to the photocells, then $v_1 + v_2 = U$, and $f_1 + f_2 = F$, and assuming that $v_{j0} = U/2$, and $f_{j0} = F/2$, the operation of the circuit can be represented by the graph shown in Fig. 5*, and a system of equations based on this graph and the above expansion into a series. Namely:

$$i_1 = \sigma_1 v_1 + \alpha_1 f_1 + i_{1n} \tag{1}$$
$$i_2 = \sigma_2 v_2 + \alpha_2 f_2 + i_{2n} \tag{2}$$
$$v = \frac{U}{2} - v_1 + v_o \tag{3}$$

Here $\underline{v}$ is the voltage across the diagonal, and $v_0$ is the potential with respect to which the points of the bridge supply potentials are equal to each other in their absolute values. $i_{jn} = i_{jp} + i_{jk}$, where

$$i_{jk} = i_j\left(\frac{U}{2}, \frac{F}{2}\right) - \sigma_j \frac{U}{2} - \alpha_j \frac{F}{2}$$

is the photocell constant obtained by linear extrapolation (at the point where $v_{j0} = U/2$, $f_{j0} = F/2$) of the values of function $i_j$ up to the point $v_j = 0$, $f_j = 0$†.

Let us also note that $f_1 = f_1^0 + N_1\vartheta$ anf $f_2 = f_2^0 - N_2\vartheta$, where $f_1^0$ and $f_2^0$ are the values of luminous fluxes which determine the voltage in the bridge diagonal corresponding to the initial ("zero") reading, and $\vartheta$ is the angle of rotation of the mirror. Hence $f_1 - f_2 = f_1^0 - f_2^0 + (N_1 + N_2)\vartheta$.

If we introduce the notation

$$i = i_1 - i_2, \quad N = N_1 + N_2, \quad f = N\vartheta,$$
$$f_s = f_1^0 - f_2^0, \quad \sigma = \frac{1}{\varrho} = \sigma_1 + \sigma_2, \quad \Delta\sigma = \sigma_1 - \sigma_2,$$
$$\alpha = \frac{\alpha_1 + \alpha_2}{2}, \quad \Delta\alpha = \alpha_1 - \alpha_2,$$

we shall obtain from (1) - (3)

$$i = -\sigma v + \alpha f + I(F, U), \tag{4}$$
$$I(F, U) = \left(\Delta\alpha\frac{F}{2} + \alpha f_s\right) + \left(\Delta\sigma\frac{U}{2} + \sigma v_0\right) + (i_{1n} - i_{2n}) \tag{5}$$

It will be seen from (5) that by adjusting the luminous flux $f_s$ and voltage $v_0$ within a limited range it is possible to compensate the bridge imbalance due to the lack of identity in the photocells. The extent to which it is possible to consider (5) as an interference

$$\varrho i = -v + \alpha\varrho f \tag{6}$$

*In Fig. 5 the values under the brackets represent the voltage drops across the corresponding photocells, whereas, the remaining notations represent potentials with respect to the grounded end of the bridge diagonal.

† Both currents $i_{jk}$ and $i_{jp}$ are small. In fact, for $v_j = 0$, but with $f_j \to 0$ we shall obtain a value approaching a shaded current

Equation (6) can also be arrived at by idealizing the working conditions of photocells [$i_{1n} = i_{2n} = 0$, $v_0 = 0$, $\sigma_1 = \sigma_2$, $\alpha_1 = \alpha_2$, $f_s = 0$, compare with (4), (5) ]. In a stable-state condition ($i = 0$ for $I = 0$)

$$v = A\Theta, \tag{7}$$

$$A = \alpha\varrho\frac{F}{\theta}, \tag{8}$$

where $\Theta$ is the angular width of the light spot with respect to the illuminator. We always have $f/\vartheta = F/\Theta = N$. The dimensions of the quantities given in (8) are:

$$\alpha = 10^{-4}\ \text{amp/lu},\ \rho \approx 10^{9}\ \text{ohm},\ F \approx 10^{-2}\ \text{lu}.$$

Photovaristor bridge. Let us now examine a photovaristor bridge with a diaphragm and a mask of a simple type, without a grid (Fig. 2). With the assumptions made in the previous section and by using Fig. 4 and by analogy with Fig. 5 we obtain for the photovaristors with an additional shaded conductivity $\sigma_{mj}$ and an additional conductivity $\omega_j$ per unit of luminous flux the equations:

$$i_1 = (\sigma_{m1} + \omega_1 f_1)\ v_1 + i_{1n} \tag{9}$$

$$i_2 = (\sigma_{m2} + \omega_2 f_2)\ v_2 + i_{2n}, \tag{10}$$

whence with the help of (3), the relation $U = v_1 + v_2$ and the notations:

$$\Delta\omega = \omega_1 - \omega_2,\ \omega = \omega_1 + \omega_2,\ \sigma_m = \sigma_{m1} + \sigma_{m2},\ \Delta\sigma_m = \sigma_{m1} - \sigma_{m2}:$$

we obtain:

$$i = -\left(\sigma_m + \frac{F}{2}\omega + \frac{f_s}{2}\Delta\omega\right)v + \frac{1}{2}\left(\frac{U}{2}\omega + v_0\Delta\omega\right)f - \frac{1}{2}\Delta\omega v f + I(U, F); \tag{11}$$

$$I(U, F) = \left(\sigma_m v_0 + \Delta\sigma_m\frac{U}{2}\right) + \frac{1}{2}\left(\frac{U}{2}\omega + v_0\Delta\omega\right)f_s + \frac{F}{2}\left(\frac{U}{2}\Delta\omega + v_0\omega\right) + (i_{1n} - i_{2n}). \tag{12}$$

Formulas (11) and (12) are similar to (4) and (5). Considering that a partial compensation of errors in (12) is possible by varying $v_0$ and $f_s$ and neglecting the small terms $\frac{1}{2}\Delta\omega\, vf$ and $i_{1n} - i_{2n}$ we shall obtain (6) if we assume that

$$\varrho = \frac{2}{F\omega + 2\sigma_m + f_s\Delta\omega}; \tag{13}$$

$$\alpha = \frac{U}{4}\omega + \frac{1}{2}v_0\Delta\omega. \tag{14}$$

Thus, the basic equations of bridges with photocells and photovaristors are the same if they are presented in the form (6).

Coefficient A for photovaristors [compare with (7) and (8) ] have the form:

$$A = \frac{\dfrac{U}{2\theta} + \dfrac{v_0}{\theta}\cdot\dfrac{\Delta\omega}{\omega}}{1 + \dfrac{2\sigma_m}{F\omega} + \dfrac{f_s}{F}\cdot\dfrac{\Delta\omega}{\omega}}. \tag{15}$$

For cadmium-sulfite photovaristors $2\sigma_m \approx 10^{-6}\ \text{ohm}^{-1}$, $\omega \approx 3\cdot10^{-3}$ amp/lu · v and normally $F \approx 10^{-2}$ lu, hence $2\sigma_m/F\omega \ll 1$ (compare with [2]). In photovaristors of other types this ratio can be nearer unity.

Equivalent circuit of a photoelectric bridge and its transfer function. It follows from the preceding that different types of bridges can be represented by the same equation. Let us derive such a generalized equation for a bridge in a dynamic operating condition with its loading taken into account.

By detonating $\alpha\rho f$ by $E_f$, it is possible to represent (6) in the form:

$$\varrho i = E_f - v \tag{16}$$

Let us account for the grid current at the amplifier input. For this purpose let us use the linearization of the grid characteristic (Fig. 6):

$$r_g i_g = E_{g0} - v. \tag{17}$$

The actual characteristics is also accounted for if we replace $E_{g0} = i_{g0} r_g$ by $E_g = (i_{g0} + \Delta i_g) r_g$, where $\Delta i_g$ is the difference between the ordinates of the actual and the linearized characteristics. Equations (16) and (17) make it possible to represent the bridge by an equivalent circuit in which network $R_k$ $C_k$ represents the load of two parallel emfs with internal resistances of $\rho$ and $r_g$. Figure 7 transforms the circuit to one source of emf

$$E = \frac{1}{\varepsilon}[E_f + (i_{g0} + \Delta i_g)\varrho] \tag{18}$$

with an additional resistance of

$$r = \frac{\varrho}{\varepsilon}; \quad \left(\varepsilon = 1 + \frac{\varrho}{r_g}\right) \tag{19}$$

$\Delta i_g \rho$ or $(i_{g0} + \Delta i_g)\rho$ can be considered as an interference. Considering the above, circuit in Fig. 7 can be represented by a system of equations which is reduced after excluding currents to a single equation (given in an operational form):

$$\frac{\eta+1}{\varepsilon}\left(\frac{\tau_4}{\eta+1}s+1\right)E = (\xi+1)\left(\frac{\tau_3}{\xi+1}s+1\right)v \tag{20}$$

$$\tau_3 = (r+R_k)C_k \quad \tau_4 = R_k C_k, \quad \eta = \frac{\tau_4}{\tau_u}, \quad \xi = \frac{\tau_3}{\tau_u},$$

$\tau_u = R_u C_k$, where $R_u$ is the leakage resistance of capacitor $C_k$.

It will be seen from (20) that the presence of a grid current and leakage reduces the time constant and the gain of the circuit. It is necessary to meet the relations $r_g \gg \rho$ and $R_u \gg (\rho + R_k)$. If these relations are met, equation (20) is reduced to

$$v = a\varrho\frac{\tau_4 s+1}{\tau_3 s+1}f, \tag{21}$$

an operator which is used in [6]. This also provides a justification for the use of equation (16) in representing the bridge.

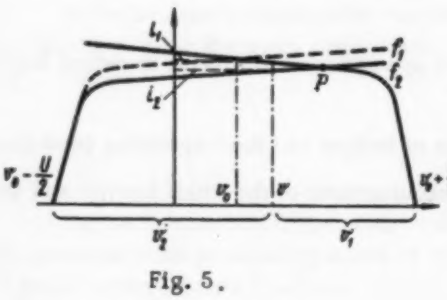

Fig. 5.

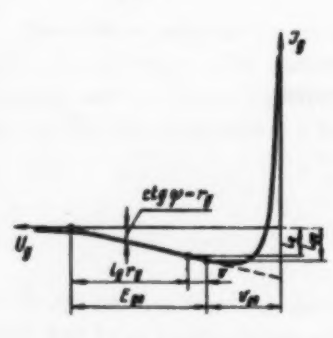

Fig. 6.

Comparative characteristics of different type bridges and their operating conditions. Let us note the peculiarities of bridges with photocells and photovaristors. The most important of them consist of sensitivity, proportional illumination, small nonlinear distortions and strict requirements with respect to leakage resistances in the case of photocell bridges; and an inappreciably smaller sensitivity [with respect to $U/2$: $v_{max}$ $\Theta/\vartheta_{max}$, which follows from (15) and (8)], which is proportional to supply voltage U (15), the existence of unavoidable [for $\Delta\omega \neq 0$ (11)] nonlinear distortions, but considerably less stringent requirements with respect to leakage resistances and the grid current in the case of photovaristor bridges (19) and (20). In addition we should consider factors not covered by the above theory, namely, the higher noise level and inertia of photovaristors. The first property limits the bridge sensitivity and the second the accuracy of its operation in a dynamic condition.

Depending on the value of the parameters and conditions of measurement, the bridges have to operate under different conditions. It follows from the physical meaning of (16) and Fig. 7 (an emf source with a load) that for $R_k \ll \rho$ voltage v is affected to a great extent by the degree to which the transient process has been completed and v is only

approximately proportional to $E_f$ (and hence to $\underline{f}$ and $\vartheta$) in a stable-state condition (first condition). At the beginning of the transient process $E_f$ is proportional to current $\underline{i}$ (second, transient condition). If $R_k \gg \rho$, then $\underline{v}$ is proportional to $E_f$ practically at any time (third condition). The first and third conditions are used in the majority of photoelectric fluxmeters and photoelectric amplifiers and compensators ($\tau_3 \ll T_e$, where $T_e$ is the time interval required for measurements), the second condition is used in the Kapitsa circuit [5] ($\tau_3 \gg T_e$). The graph in Fig. 5 represents the second condition. In the remaining conditions the points on the curve with abscissas $\underline{v}$ coincide with sufficient accuracy with the curves' intersection point P, when $i_1 \approx i_2$.

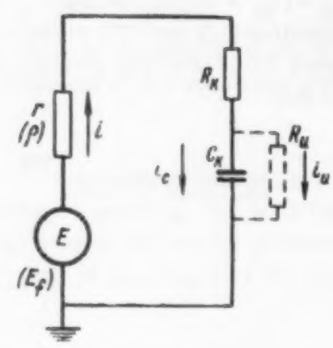


Fig. 7.

The above formulas hold if the photocells are shunted by ohmic resistances. The only difference this shunting produces consists in the fact that the graphs and corresponding parameters which are similar to those given above, instead of referring to the photocells alone, apply to their combination with the parallel resistors.

In analyzing vacuum photocell bridges in a more complete manner it is necessary to consider the input capacitance of the electronic amplifier.

The sensitivity of the bridge can be raised considerably by using grid diaphragms and masks [1], [2].

In such a version of the instrument the proportion of the luminous flux which varies with the rotation of the mirror is raised, thus raising, for the same total angular width $\Theta$ of the illuminated photovaristor portion, the conversion factor A proportionately to the number $\underline{n}$ of slots in the diaphragm [in (15) a multiplier $\underline{n}$ is introduced]. It can be easily shown that the number of slots must satisfy the inequality

$$\frac{\Theta}{2n} > \vartheta_{max} \gg \vartheta_b, \tag{22}$$

where $\vartheta_{max}$ corresponds approximately to the maximum value of the measured quantity or the maximum rate of its measurement (in integrating instruments without a feedback), and $\vartheta_b$ corresponds to an interference level permissible for a given accuracy, including the noise level and the level of amplitude distortions*. The latter may be due to the light beam defraction by the mirror and the grid nonlinearity caused by term $\Delta\,\omega$ vf (11).

Conclusions. The basic result of this work consists in a rigorously derived equation for a bridge with photoelements working in a dynamic condition (21) and in derived relations [formulas (4)-(8), (11)-(15) and (18)-(20)], which provided a more detailed analysis than hitherto of various bridge designs, as well as facilities for their computation.

It follows from formulas (5) and (12) that it is possible by means of appropriate adjustments to reduce the effect of the supply voltage and illumination on the position of the "zero."

The above theory brings to light the peculiarities of different types of bridges and their operating conditions.

The applicability range of the above theory is determined by the requirements of the small inertial and the quasilinear characteristic of the photoelements.

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*It is impossible to derive in this article a more accurate relationship, since the theory required for this purpose would include that of the instrument in which the bridge is used.

# HIGH AND ULTRAHIGH FREQUENCY MEASUREMENTS

## ERRORS IN MEASURING THE REFLECTION COEFFICIENT OF GROUND

A. A. Kotovich

Translated from Izmeritel'naya Tekhnika, No. 4, pp. 34-37

For measurements at 25-400 Mc,field-strength measuring sets are placed in a standard field provided by a dipole suspended over the surface of the earth. The field strength can be determined from the formula:

$$|\dot{E}_{on}| = \frac{60\pi I l_{\partial}}{\lambda}\left|\frac{1}{r_1} + \frac{\dot{R}e^{-j2\pi(r_2-r_1)/\lambda}}{r_2} + \delta\right|, \tag{1}$$

where $|\dot{E}_{on}|$ is the effective value of the field strength, due to a horizontal dipole in the equatorial plane, taken in a direction normal to the dipole of a distance from its middle of $d \geq 2\rho$, v/m; I is the effective value of current, amp; $l_e$ is the effective antenna length, m; $\dot{R}$ is the complex reflection factor from ground; $\rho$ is the wavelength, m; $r_1$ and $r_2$ are the distances covered by the direct and reflected rays, m; $\delta$ are the terms of the equation, which can be neglected as compared with the first terms.

In (1) the first term corresponds to the direct wave, the second to the reflected wave. Since the reflection factor changes depending on the type and condition of the soil, the resultant field strength can be calculated if the ground reflection factor is known.

In the present article the errors in determining the ground reflection coefficient are examined.

The complex reflection factor in a general case is represented in the form:

$$\dot{R} = |\dot{R}|\,e^{-j\Theta} \tag{2}$$

In the frequency range under consideration angle $\Theta$ of the reflection factor approaches 180° for a horizontal polarization, since the earth conductance currents are considerably smaller than the displacement currents ($\sigma \ll \varepsilon'\omega$ [1]). Hence:

$$\dot{R} \approx -|\dot{R}|. \tag{3}$$

The reflection coefficient can be determined from relative field measurements in the vertical plane similar to the measurements of standing waves in measuring lines. The generator consists of a transmitting dipole, the probe of the receiving dipole fixed to a moving carriage, and the load consists of the ground [2].

The device consists of a vertical wooden mast on which the transmitting and receiving diploes are mounted parallel to each other. The transmitting dipole is mounted at the top of the mast in a fixed position at height $h_1$ from the ground, and the receiving dipole is moved between the ground and the transmitting dipole, its height is denoted by $h_2$. In this case distances $r_1 = h_1 - h_2$ and $r_1 = h_1 + h_2$, and equation (1) assumes the form:

$$|\dot{E}_{on}| = \frac{60\pi I l}{\lambda}\left|\frac{1}{h_1-h_2} + \frac{|\dot{R}|e^{-j(4\pi h_2/\lambda+\Theta)}}{h_1+h_2}\right|. \tag{4}$$

It will be seen from (4) that at the points corresponding to $4\pi h_2/\rho + \Theta = 2\pi n$ (where n = 1,2,3. . .) the field strength will have its maximum values $|\dot{E}_{on}|_{max}$, and at the points $4\pi h_2/\rho + \Theta = 2(n-1)\pi$ it will have its minimum values $|\dot{E}_{on}|_{min}$. The ratio of $|\dot{E}_{on}|_{max}/|\dot{E}_{on}|_{min}$ gives the value of the standing wave ratio:

$$k=\frac{|\dot{E}_{on}|_{max}}{|\dot{E}_{on}|_{min}}=\frac{\frac{1}{(h_1-h_{2max})}+\frac{|\dot{R}|}{(h_1+h_{2max})}}{\frac{1}{(h_1-h_{2min})}-\frac{|\dot{R}|}{(h_1+h_{2min})}}. \tag{5}$$

Solving (5) with respect to $|\dot{R}|$, we obtain:

$$|\dot{R}|=\frac{\frac{k}{h_1-h_{2\,min}}-\frac{1}{h_1-h_{2\,max}}}{\frac{k}{h_1+h_{2\,min}}+\frac{1}{h_1+h_{2\,max}}} \tag{6}$$

It will be seen from (6) that the value of the ground reflection factor can be determined if heights $h_{2max}$ and $h_{2min}$ are known as well as the corresponding field strengths $|\dot{E}_{on}|_{max}$ and $|\dot{E}_{on}|_{min}$.

On the basis of the duality theory we can write:

$$|\dot{E}_{on}|=|\dot{E}_{oa}|.$$

Here $|\dot{E}_{oa}|$ is the field strength determined by the reference antenna method

$$|\dot{E}_{oa}|=\frac{e}{l_e}, \tag{7}$$

where $\underline{e}$ is the emf induced in the receiving dipole, and $l_e$ is the effective antenna length.

Hence

$$k=\frac{|\dot{E}_{on}|_{max}}{|\dot{E}_{on}|_{min}}=\frac{|\dot{E}_{oa}|_{max}}{|\dot{E}_{oa}|_{min}}=\frac{e_{max}}{e_{min}}. \tag{8}$$

In an actual dipole loaded by impedance $\dot{z}_l$ we do not measure the emf $\underline{e}$ but the voltage $u_l$ across the above load.

Therefore:

$$k=\frac{u_{max}}{u_{min}}(1+\Delta), \tag{9}$$

where $\Delta$ is the systematic relative error whose value depends on the measuring conditions.

By substituting $\underline{k}$ in (6) with its value obtained from (9) we have:

$$|\dot{R}|=\frac{\frac{u_{e\,max}/u_{e\,min}}{(h_1-h_{2min})}(1+\Delta)-\frac{1}{(h_1-h_{2\,max})}}{\frac{u_{e\,max}/u_{e\,min}}{(h_1+h_{2\,min})}(1+\Delta)+\frac{1}{(h_1+h_{2\,max})}}. \tag{10}$$

Let us determine the conditions for which $\Delta \ll 1$.

For this purpose let us examine our system, consisting of the transmitting and receiving dipoles placed above the actual ground, as if it were a quadripole (see Fig.). Here 1, 2 are the radiating dipole and its mirror image, and 3, 4 are the receiving dipole and its mirror image.

Let us derive an equation for the currents and voltages.

$$\left.\begin{aligned} e_{on}&=\dot{I}_1(\dot{z}_{11}-|\dot{R}|\,\dot{z}_{12})+\dot{I}_3(\dot{z}_{13}-|\dot{R}|\,\dot{z}_{14})\\ 0&=\dot{I}_1(\dot{z}_{31}-|\dot{R}|\,\dot{z}_{32})+\dot{I}_3(\dot{z}_{33}-|\dot{R}|\,\dot{z}_{34})\end{aligned}\right\}. \tag{11}$$

where $e_{on}$ is the emf in the transmitting dipole; $I_1$ is the current in the transmitting dipole; $I_3$ is the current in the receiving dipole, $z_{nn}$ is the self-impedance of the dipoles; and $z_{nm}$ is the mutual impedence of the dipoles.

By solving (11) with respect to current $I_3$ and assuming that the current distribution in the dipoles is sinusoidal, we obtain:

$$I_3 = -I_1 \frac{\dot{z}_{31} - |\dot{R}|\,\dot{z}_{32}}{\dot{z}_{33} - |\dot{R}|\,\dot{z}_{34}}. \tag{12}$$

During measurements, impedance $\dot{z}_l$ is connected to the circuit of the receiving dipole, hence the total impedance of the dipole will be $\dot{z}_l + \dot{z}_{33} - |R|\dot{z}_{34}$, and the current in the receiving dipole will be:

$$I_3 = -I_1 \frac{\dot{z}_{31} - |\dot{R}|\,\dot{z}_{32}}{\dot{z}_1 + \dot{z}_{33} - |\dot{R}|\,\dot{z}_{34}}. \tag{13}$$

The emf induced in the receiving dipole is:

$$e = I_3 (\dot{z}_1 + \dot{z}_{33} - |\dot{R}|\,\dot{z}_{34}). \tag{14}$$

The voltage across the load impedance $\dot{z}_l$ is

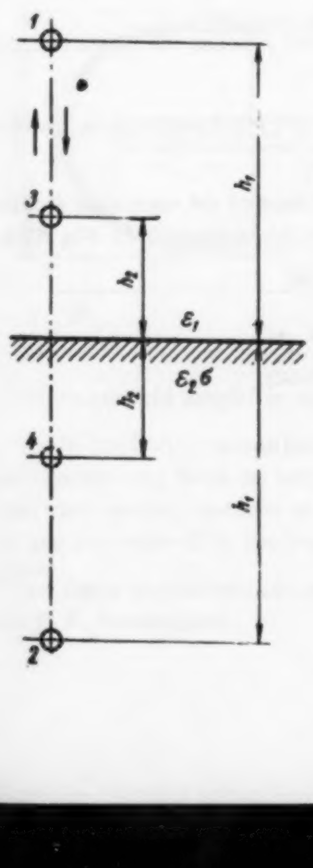
$$u_H = \dot{I}_3 \cdot \dot{z}_H. \tag{15}$$

By inserting in (9) the values obtained for $\underline{e}$ and $u_l$ from (13), (14) and (15), and solving it with respect to $\Delta$, we obtain

$$\Delta = |\dot{R}| \frac{|\dot{z}_{34\min}| - |\dot{z}_{34\max}|}{|\dot{z}_1 + \dot{z}_{33} - |\dot{R}|\,\dot{z}_{34}}. \tag{16}$$

The numerator in (16) increases with an increasing $|\dot{R}|$ and a decreasing height of the receiving dipole above ground.

$$\left(\dot{z}_{34} \approx j\,\frac{30\lambda}{\pi h_2}\,e^{-j4\pi h_2/\lambda}\right).$$




The value of the denominator depends on the sum $|\dot{z}_1 + z_{33} - |R|z_{34\min}|$. Hence, the error $\Delta$ rises with a decreasing height, and its absolute value will grow with an increasing $|\dot{R}|$ and a decreasing sum of $|\dot{z}_1 + z_{33} - |\dot{R}|z_{34\min}|$.

Calculating show that in the case of a half-wave dipole and $|\dot{z}_1| \approx |\dot{z}_{33}|$ the error $\Delta \approx 0.1$. If $|\dot{z}_1| >> |\dot{z}_{33}|$ then $\Delta \ll 0.005$ (moreover, $h_2 < 0.5\,\lambda$ and $|\dot{R}| \approx 0.8$).

Experimental checks have confirmed the calculations within the limits of accuracy of measurement (Table 1).

From the above data it will be seen that the systematic error examined by us can be reduced to a negligible value if measurements are made with the dipole which has $|\dot{z}_1| >> |\dot{z}_{33}|$ and $h_2 \geq 0.5\,\lambda$.

In this case the error in measuring the ground reflection coefficient will only be determined by random errors in measuring the quantities in (10).

$$\xi_R = \sqrt{\left(\frac{\partial R}{\partial k}\right)^2 (\xi_k)^2 + \left(\frac{\partial R}{\partial h_{2\max}}\right)^2 (\xi_{h_2\max})^2 + \left(\frac{\partial R}{\partial h_{2\min}}\right)^2 (\xi_{h_2\min})^2}\,. \tag{17}$$

where $\xi_k$ is the minimum error of 1.5% in measuring the standing wave factor k, and $\xi_{h_2\max}$, $\xi_{h_2\min}$ are the maximum random errors of 1% in measuring the heights $h_{2\max}$ and $h_{2\min}$ respectively.

The partial errors comprised in (17) increase with the height $h_2$ of the dipole, since the different $h_1 - h_{2max}$ and $h_1 - h_{2min}$ which are included in (10) will then decrease, but the absolute value of random errors $\varepsilon\, h_{2max}$ and $\varepsilon\, h_{2min}$ will remain the same.

TABLE 1

| $h_{2max}$ (m) / $h_{2min}$ (m) | Δ, % | | Note |
|---|---|---|---|
| | Calculation | Experiment | |
| 0.5/1 | 8.2 | 10.5 | $f$ = 150 Mc |
| 1.5/1 | 2.6 | 2.2 | $\lvert\dot{z}_1\rvert \approx \lvert z_{33}\rvert$ |
| 1.5/2 | 1.2 | 1.9 | $\lvert\dot{R}\rvert \approx 0.64$ |

TABLE 2

| $h_{2max}$(m) / $h_{2min}$(m) | 5.5/6 | | 3.5/4 | | 1.5/2 | | Note |
|---|---|---|---|---|---|---|---|
| $\lvert\dot{R}\rvert$ | 0.8 | 0.2 | 0.8 | 0.2 | 0.8 | 0.2 | $h_1$ = 10.7 m |
| $\varepsilon_R$, % | 4.8 | 17.2 | 3.5 | 9.3 | 1.1 | 4.2 | $f$ = 150 Mc<br>$\lvert\dot{z}\rvert >> \lvert\dot{z}_{33}\rvert$ |

The error in determining the reflection coefficient also grows as its value decreases, since the partial error $(\partial R/\partial K)\ \varepsilon_k$ grows with a decreasing k.

Hence, the random error in determining $\lvert\dot{R}\rvert$ grows with an increasing height of the receiving dipole and decreasing reflection factor.

Table 2 shows the calculation results of the errors for two values of $\lvert\dot{R}\rvert = 0.8$ and $\lvert\dot{R}\rvert = 0.2$ for a varying dipole height of $0.5\lambda < h_2 \leq 3\lambda$.

TABLE 3

| $h_{2max}$(m) / $h_{2min}$(m) | $\lvert\dot{R}\rvert_1$ | $\lvert\dot{R}\rvert_2$ | $\lvert\dot{R}\rvert_3$ | $\lvert\dot{R}\rvert_4$ | $\lvert\dot{R}\rvert_5$ | Note |
|---|---|---|---|---|---|---|
| 2.5/3 | 0.713 | 0.744 | 0.731 | 0.404 | 0.223 | j = 150 Mc<br>$h_1$ = 10.76m |
| 2.5/2 | 0.701 | 0.708 | 0.705 | 0.390 | 0.219 | |
| 3.5/3 | 0.726 | 0.743 | 0.720 | 0.407 | 0.200 | |
| $\lvert\dot{R}\rvert_m$ | 0.715 | 0.720 | 0.713 | 0.402 | 0.212 | |
| $\delta R$, % | 2.4 | 2.7 | 2.5 | 3 | 5.7 | |

It will be seen from Table 2 that the error $\varepsilon_R$ in the above cases may amount to 17%.

It follows from the above that the upward and downward movement of the adjustable dipole must be limited. The upward movement of the dipole should be limited owing to the rise in the relative error of measurement of the difference $h_1 - h_{2max}$ and $h_1 - h_{2min}$, and its downward movement owing to the increased effect of the dipole mirror image field of the dipole itself. Hence, there is an optimum position for the dipole, determined by the height $h_1$ of the mast and the wavelength at which the measurements are made.

Table 3 gives the results obtained in measuring ground reflection factors taking into account the above conclusions that $\lvert\dot{z}_1\rvert >> \lvert\dot{z}_{33}\rvert$ and $0.5\lambda \leq h_2 \leq 2\lambda$.

Conclusions. The ground reflection factor can be determined in the range of 25-400 Mc from relative measurements of field strength in a vertical plane.

In order to raise the accuracy of measurements it is necessary that the load impedance of the receiving dipole should be considerably larger than its input impedance and that its height should vary in the range of $0.5\lambda \leq h_2 \leq 2\lambda$ (for $h_1 \approx 5\lambda$ = const).

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# RADIATION MEASUREMENTS

## TISSUE-EQUIVALAENT DOSIMETER FOR FAST NEUTRONS

M. F. Yudin and O. A. Filippov

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The object of our work consisted in developing a dosimeter which would measure doses due to fast neutron fluxes of a densisty of 20-30 neutrons/cm$^2$·sec and more, and would possess a relation of its readings to the energy of neutrons similar to that of an absorbed dose in a soft tissue to the energy of neutrons irradiating that tissue.

Among the instruments of this type described in literature, the best characteristics are possessed by tissue-equivalent ionization chambers suggested by Failla and Rossi [1, 2, 3] and Hurst's tissue-equivalent proportional counter [4, 5, 6]. The disadvantage of the first type of instrument consists in the difficulty of separating the $\gamma$-rays from the neutron dose; the instruments of the second type do not register protons whose energy is below their discrimination level.

An average soft biological tissue of a compound of $(C_5H_{40}O_{18}N)_n$ can be simulated satisfactorily for fast neutrons by a material containing by weight approximately 10% of hydrogen and 90% of carbon. This material can be obtained by mixing graphite with polythene.

The tissue-equivalent chamber of our dosimeter were made of a compressed and carefully mixed powder consisting of 2.4 parts by weight of polythene and one part graphite*. The surface of components after compression was homogeneous and smooth, which is important for decreasing the absorption gases on the walls of the chamber. The conductivity of this material was found to be good, but the surface conductivity was uneven in different parts of the chamber. The calibration of the chamber in a field of $Co^{60}$ $\gamma$-rays showed that this circumstance did not affect appreciably the value of the ionization current. In order to meet the conditions of radiation equilibrium and eliminate any diffusion of gas through the walls, they were made 5 mm thick and the chambers volume was made equal to 953 (±3) cm$^3$. The central electrode of the chamber was made of the same plastic and mounted in the chamber by means of a polystyrol polished insulator, whose leakage currents were negigibly small as compared with the measured ionization currents.

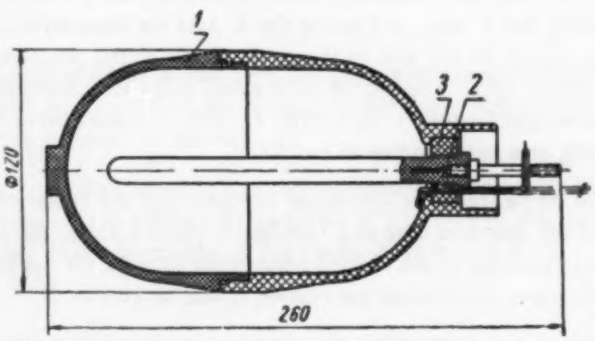


Fig. 1.

The schematic of the device and the appearance of the ionization chamber are shown in Figs. 1 and 2. The body of the chamber consists of two parts. These parts are glued together with ÉDS-5 epoxy resin mixed with pure polyamine. This mixture polymerizes rapidly at room temperature. The same mixture was used for fixing the internal chamber electrode on its insulator and for mounting the insulator in the body of the chamber.

We also had the equipment necessary for evacuating the chamber, filling it with the required gas composition and sealing it off hermetically from the surrounding medium.

Electrometer devices. For measuring the ionization currents produced by the radiations in the chamber we used an electrometric amplifier type ÉMU-3 and an electrometer dosimeter type DIM, made by the "Étalon" plant.

In the ÉMU-3 amplifier we used a type KVM resistor. Resistors of that type are stable with time and their value depends very little on temperature or humidity. It is possible to measure by means of ÉMU-3 instruments fitted with such resistor currents as low as $2 \cdot 10^{-14}$ amp. In measuring $2 \cdot 10^{-13}$ to $3 \cdot 10^{-11}$ amp the readings of the ÉMU-3 set are proportional to the measured current.

*The tissue-equivalent chamber was made with the assistance of the Institute of Polymerized Plastics (A. V. Golubeva and P. P. Novozhilov).

For a more stable operation of the instrument, its input was connected in parallel with a $20 \mu\mu$ f ceramic condenser, whose leakage resistance was at least twice as large as the input resistance. The relative error in measuring the current by means of the ÉMU-3 instrument amounted to $\pm(5-8)\%$.

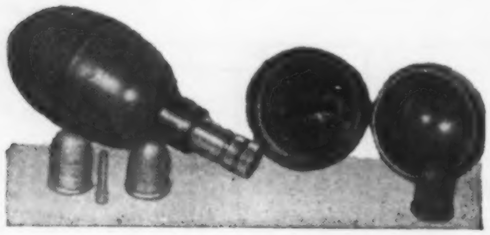

Fig. 2.

The electrometer device of the DIM instrument is shown schematically in Fig. 3 and consists of a quadrant electrometer. The stabilized voltage of 300 v is fed to the chamber through a doubly screened coaxial cable. The internal screen is connected to a voltage equal to that on the chamber collector electrodes. By means of this electrometer we measured either the voltage across the plates of an amber insulated capacitor, or the voltage drop across a resistor which passed the ionization current. In the first instance the electrometer readings are proportional to the total dose, and in the second to the power of the dose.

When the ionization current is measured by means of the DIM instument the body of the chamber is grounded and the positive potential is fed to the internal electrode. When the ÉMU-3 instrument is used it is necessary to feed the negative voltage to the body of the chamber and place the entire chamber in an electrostatic screen. The DIM instrument provides a more accurate measurement of the dose than the ÉMU-3 instrument, but it is not sufficiently sensitive, and it can only be used for measuring currents corresponding to the power of an absorbed dose exceeding 20 $\mu$ rads/sec.

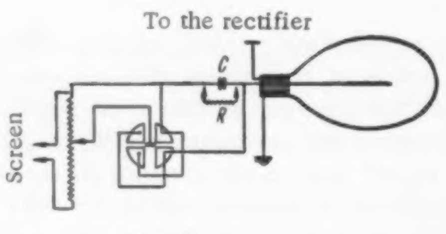


Fig. 3

Investigation of tissue-equivalent ionization chambers. In order to establish the situation potential, curves were plotted of the relationship between the ionization current and the potential in the chamber for different dosage powers. For a maximum ionization current of $1.6 \cdot 10^{-11}$ amp the saturation potential amounts to 200 v. The chamber operating voltage was set at 300 v. At first the chamber was calibrated in $\mu$ rads per sec when operating with ÉMU-3 instruments and irradiated with $Co^{60}$ $\gamma$-rays.

The calibration was made with the chamber filled with methane, air and a tissue-equivalent gas mixture (partial pressures of methane 64.5%, carbon dioxide 32.5%, nitrogen 3.1%) at pressures up to 760 mm Hg.

The relation between the ionization current and the dosage power of $\gamma$-radiations, as well as the ÉMU-3 instrument readings based on these calculations and showing the power of the absorbed dose in $\mu$ rads/sec, are given in Fig. 4. In this figure the $\gamma$-radiation dosage power is plotted along the Y axis, and along the X axis the ionization current due to $Co^{60}$ $\gamma$-radiations in the chamber with its center placed on the axis of the $\gamma$-ray beam at the points whose dosage powers are shown on the X axis. The graphs were taken when the chamber was filled with the tissue-equivalent gas (curve 1), air (curve 2), and methane (curve 3) with pressures up to 760 mmHg at a temperature of t = 18°C.

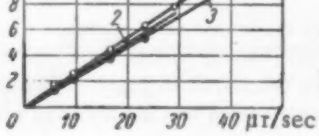


Fig. 4.

Figure 5 shows the relation between the dosimeter readings and the power of the absorbed dose. The power of the absorbed dose in $\mu$ rads/sec is plotted along the X axis, and along the Y axis the readings of the ÉMU-3 instrument in volts for the ionization chamber filled with the tissue-equivalent gas (curve 1) and air (curve 2).

It will be seen from Figs. 4 and 5 that when the chamber is placed in a diaphragm-directed beam of $Co^{60}$ $\gamma$-rays, the ionization current in a chamber filled with methane or air is 15-17% and 8-11%, respectively, lower than the current in a chamber filled with the tissue-equivalent gas up to the same pressure of 760 mmHg.

In other words, for the same power of an absorbed $\gamma$-radiation dose in $\mu$ rads/sec the readings of an instrument for a chamber filled with air will be smaller than those for a chamber filled with the tissue-equivalent gas by the amount of 8-11%.

The difference in ionization currents of 10% is due to the different stopping powers of the tissue-equivalent gas and air, and differences in the ionization work.

Table 1 shows the relative stopping powers of the tissue-equivalent gas with respect to air and the ionization work of electrons [7].

The value of S, given in Table 1 for the tissue-equivalent gas, hold if the stopping powers of the gas mixtures are additive.

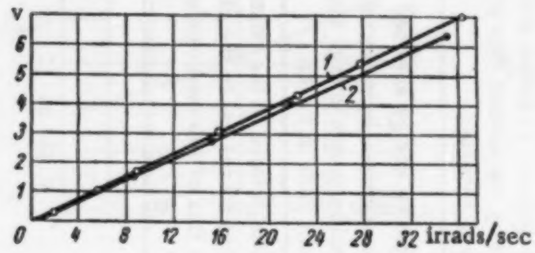


Fig. 5.

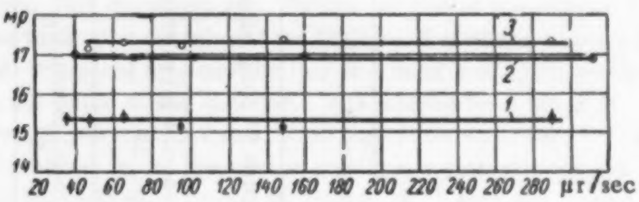


Fig. 6.

In Fig. 6 are shown the calibration results of a chamber working with a DIM No. 4 instrument in a field of $\gamma$-rays. Along the X axis we have plotted the power of the $\gamma$-ray dose, and along the Y axis the $\gamma$-ray dose, i. e., the product of the dosage power and time for which the instrument pointer was displaced over scale divisions (from 4 to 14 "$\mu$r" scale divisions). A deflection of 10 divisions corresponds to an absorption of a dose of 15.9 mrads, if the chamber is filled with the tissue-equivalent gas, and to 15.7 mrads, if the chamber is filled with air, both being at the pressure of 760 mmHg and a temperature of 18°C. The calibration of the chamber filled with air and used with the DIM instrument was checked for 9 months. Owing to the aging of the chamber itself the calibration changed in this period by 10%, leading to an increased sensitivity of $\gamma$-rays.

TABLE 1

| Name of gas | $\frac{S_{gas}}{S_{air}}$ | $\epsilon_{ev}$ |
|---|---|---|
| Air | 1.00 | 34.0 |
| $CO_2$ | 1.52 | 32.9 |
| $CH_4$ | 0.82 | 27.3 |
| Tissue-equivalent gas | 1.05 | 32.3 |

Computation of the current when the chamber is irradiated by neutrons. When the chamber is irradiated by neutrons and $\gamma$-rays the same ionization current will correspond to different absorbed energies.

Thus, the same ionization currents produced in an air-filled chamber by a $\gamma$-ray irradiation dose of 1 r of by a field of rapid neutrons will correspond in the latter case to a larger absorbed energy (amounting to 36/34 of the former) owing to the difference in the ionization work of electrons and protons.

Hence, if the power of the absorbed dose of neutrons is expressed in $\mu$ rads/sec, the instrument reading corresponding to an absorbed dose of 1 $\mu$rad /sec will be equal to 0.97 A, where A is the reading of the same instrument when the chamber is irradiated by $\gamma$-rays, whose irradiation dose is equal to 1$\mu$r/sec.

Before starting the measurements we calculated the ionization current which should be measured in the chamber when it is irradiated by neutrons of a Po-$\alpha$-Be source with a flux density of 100 neutrons/cm$^2$·sec. The calculations were made by means of the Bragg-Gray equation [8]:

$$P = E_n N \Sigma n_i \sigma_i f_i, \qquad (1)$$

where P is the energy absorbed in 1 second by 1 g of the medium; N is the area of the neutron flux, neutrons/cm$^2$·sec; $E_n$ is the energy of neutrons; $n_i$ is the number of i-grade atoms in 1 g of tissue; $\sigma_i$ is the cross section of neutron scatter on i-grade atoms; $f_i E_n$ is the mean energy of protons formed by collisions with neutrons.

This relation holds for a monoenergetic neutron flux. For our computations we divided the neutron spectrum from the Po-$\alpha$-Be source [9] into five energy groups and calculated for each group the energy absorbed in the chamber walls when irradiated by a flux of 100 neutrons/cm$^2$·sec. As an effective radiator mass we took one-third of the mass of the tissue-equivalent layer material, whose thickness is equal to the maximum range of recoil protons which are formed in scattering the neutrons of the given energy group. As an effective area we took two-thirds of the chamber cross sectional area. Only a part of the energy P, calculated from (1), will be absorbed by the gas in the chamber. The value of this fraction depends on the extent to which the recoil proton paths will fit into the working volume of the chamber.

TABLE 2

| Energy of neutrons, $E_n$, Mev | Neutron cross section for $N\sigma_s^n$, barn | Number of neutrons of a given energy in the flux of 100 neutrons/sec $\Delta N$ | Mean energy of recoil protons $\bar{E}_n$, Mev | Tissue proton range $R_t$, mg/cm$^2$ | Total energy transferred by recoil protons knocked out of the walls by the neutron flux of 100 neutrons/cm$^2$·sec $P_w$, Mev/sec | Portion of the proton energy absorbed by the gas in the chamber, obtained by accounting for the relations in specific proton energy losses at various parts of their path $\Delta Pn/En$ | Energy of protons, formed in the chamber walls, which is absorbed by the gas in the chamber when irradiated by a flux of 100 neutrons/cm$^2$·sec $P_{gas}$, Mev/sec |
|---|---|---|---|---|---|---|---|
| 2 | 2.9 | 14.3 | 1 | 2.5 | 2.5 | 1.0 | 2.5 |
| 4 | 1.9 | 31.2 | 2 | 7.5 | 17.8 | 0.8 | 14.2 |
| 6 | 1.4 | 31.4 | 3 | 15 | 39.5 | 0.35 | 13.8 |
| 8 | 1.1 | 17.1 | 4 | 26 | 39.0 | 0.16 | 6.2 |
| 10 | 0.94 | 7.2 | 5 | 39 | 26.4 | 0.12 | 3.2 |
| Total | — | 101.2 | — | — | 125.2 | — | 39.9 |

The computation results and data [10, 11] used in carrying them are shown in Table 2.

Let us now calculate the value of the ionization current when the chamber is filled with methane to a pressure of 760 mmHg by using the data in Table 2 for $P_{gas}$, which were calculated for a chamber filled with the tissue-equivalent gas.

The current produced only by the recoil protons knocked out of the walls is equal to

$$I = \frac{P_{gas}}{\epsilon_{CH_4}} \, 1.6 \cdot 10^{-19} = \frac{39.9}{30} \, 10^6 \cdot 1.6 \cdot 10^{-19} = 2.1 \cdot 10^{-13} \text{ amp.} \quad (2)$$

It is known that the specific absorbed energy in methane is equal to 0.634 Mev/g· sec per 1 neutron/cm$^2$·sec radiated by a Po-α-Be source.

In the effective volume of the chamber with a neutron flux of 100 neutrons/cm$^2$ · sec there will be absorbed per second an energy due to the collision of neutrons with the gas nuclei amounting to

$$P_{CH_4} M_{CH_4} \cdot 100 = 0.634 \cdot 0.680 \cdot 100 = 43 \text{ Mev/sec}, \quad (3)$$

where M is the mass of methane.

The ratio of the ionization currents due to the recoil protons knocked out of the walls and those knocked out of the gas must be greater than

$$\frac{P_W}{P_{CH_4} M_{CH_4}} > \frac{125}{43} = 2.9, \text{ or } \frac{I_{gas}}{I_W} < 0.34. \quad (4)$$

The contribution of the gas to the ionization current will in fact be smaller than 34%, since the portion of the paths packed into the chamber is larger for the protons knocked out of the walls than those due to the collision of neutrons with the gas nuclei. If we assume that the current due to other recoil nuclei which constitute the tissue-equivalent material of the chamber walls and have been knocked out of the walls by neutrons amounts to 10% of the proton current, and that the contribution of the gas ionization current amounts to not more than 20% of the current due to

protons produced in the chamber walls, the total ionization current in the chamber filled with methane to 760 mmHg and irradiatied by the flux of 100 neutrons/cm$^2$·sec should not exceed $2.2 \cdot 10^{-13} \cdot 1.30 = 2.76 \cdot 10^{-13}$ amp.

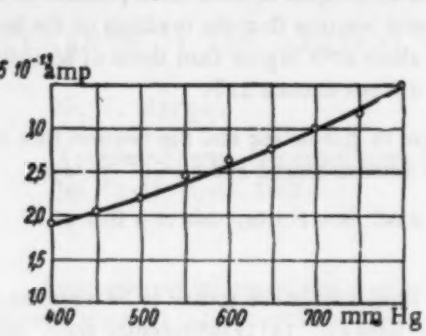


Fig. 7.

As we shall see below, a current of $2.40 \cdot 10^{-13}$ amp was obtained experimentally, i. e., the calculated data agreed with experimental results within 15-20%.

Neutron flux measurements. At first we plotted the relation between the ionization current and the pressure of methane which filled the chamber irradiated by a neutron flux of a density of 133 neutrons/cm$^2$·sec in the center of the chamber. This relation for a range of absorbed dosage powers of 0.2 to 1 $\mu$rad /sec is shown in Fig. 7. The pressure of methane in the chamber in mmHg was plotted along the X axis, and the ionization current in units of $10^{-13}$ amp was plotted along the Y axis. A Po-$\alpha$-Be source of neutrons was used.

In order to check the operation of the chamber we determined experimentally ionization currents with filtering of the neutron beam from a PO-$\alpha$-Be source by lead screens 10 and 20 mm thick and also without filtering. On the basis of 20 measuring results we determined the ratios $(I_0 - I_f)/I_0$ %, where $I_0$ is the ionization current in the chamber without lead filtering of the neutron beam, $I_f$ is the current with lead filtering. The ratio $\left(\frac{I_0 - I_f}{I_0}\right)_m$ was found to be equal to 9.7% with 10 mm lead filtering and to 15.2% with 20 mm lead filtering.

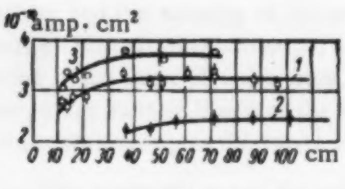


Fig. 8.

Table 3 shows the calculated data of the attenuation in lead of a neutron beam and of $\gamma$-rays from a Po-$\alpha$-Be source ($E_\gamma = 0.8$ Mev).

In calculating $I_n/I_0$, it was assumed that the full interaction cross section of neutrons from Po-$\alpha$-Be source was equal for lead to 6 barn.

Calculated on the basis of the measurement results and the data in Table 3, the contributions to the ionization current of the currents due to $\gamma$-rays amounted to 15.3% with a 10 mm filter and to 14.2% with a 20 mm filter, i.e. about 14.8% of the ionization current from a Po-$\alpha$-Be neutron source is is due to $\gamma$-rays. This produces a current of $3 \cdot 10^{-14}$ amp in methane for a neutron flux of 100 neutrons/cm$^2$·sec, which corresponds to a $\gamma$-ray dosage power of 0.1 $\mu$r/sec (see Figure 5), and exceeds slightly the power of the $\gamma$-dose given in [12] as 0.2 mr/hr at a distance of 60 cm from a source of 1 curie of polonium or 0.084 $\mu$r/sec per 100 neutrons/cm$^2$·sec.

TABLE 3

| Thickness of the lead filter, mm | $\frac{I_\gamma}{I_{\gamma_0}}$ | $\frac{I_n}{I_{n_0}}$ |
|---|---|---|
| 10 | 0.50 | 0.86 |
| 20 | 0.23 | 0.76 |

Figure 8 represents the relation of the product of the chamber ionization current and the square of the distance between the center of the chamber and the source to the distance between the chamber and the source:

$$I_k r^2 = f(r),$$

where $I_k$ is the ionization current produced by the neutrons in the chamber, and $r$ is the distance between the neutron source and the center of the chamber.

The current was measured with the chamber filled with methane (curve 3), the tissue-equivalent gas (curve 1) and air (curve 2). Deviations from a straight line parallel to the X axis at small distances from the source are apparently due to a considerable nonuniformity of the neutron field at these distances.

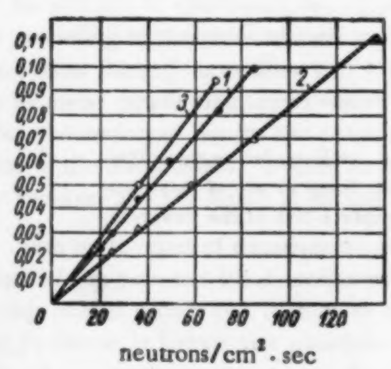


Fig. 9.

Figure 9 shows the relation of the ÉMU-3 instrument readings in volts to the density of the neutron flux from a Po-$\alpha$-Be source.

On the basis of these data it is possible to evaluate the "wall" and "gas" effects. It will be seen that the ratio of the currents in a chamber filled with methane (curve 3) and air (curve 2) is equal to 1.63 for a pressure in the chamber of 760 mmHg and a temperature of 18°C. In other words, for the same neutron flux the readings of the instrument with a chamber filled with the tissue-equivalent gas (curve 1) are about 40% higher than those of an instrument with a chamber filled with air. For $\gamma$-ray irradiations this difference did not exceed 11%.

Figure 10 shows the relation between the power of a tissue absorbed dose in $\mu$rads/sec and the neutron flux density, plotted on the basis of dosimeter calibrations by means of a Po-$\alpha$-Be neutron source and by $Co^{60}$ $\gamma$-rays.

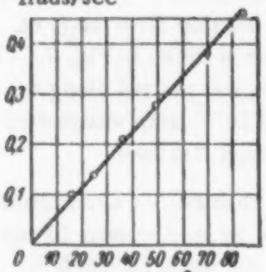


Fig. 10.

It will be seen that a dosage power of 0.2 $\mu$rad/sec corresponds to a flux of 37 neutrons/cm²·sec.

If we assume the mean energy of neutrons from a Po-$\alpha$-Be source to be equal to 3 Mev, the agreement of this result with theoretical data [13, 14] is sufficiently good. According to Snyder's calculations, the permissible neutron flux with an energy of 3 Mev corresponding to a dose of 2 $\mu$ber/sec is equal to 35 neutrons/cm²·sec. The international commission for radiological protection, meeting in Copenhagen in 1953 adopted the value of 30 neutrons/cm²·sec.

Conclusions. As a result of this work a tissue-sensitive dosimeter of fast neutrons has been produced for measuring from 0.5 to several hundred permissible tissue dose powers in $\mu$rads/sec with an error of 7-12%.

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**All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal.** ***Some or all of this periodical literature may well be available in English translation.*** **A complete list of the cover-to-cover English translations appears at the back of this issue.**

# LIQUID AND GAS FLOW MEASUREMENTS

## ELEMENTS OF THE GENERAL THEORY OF ULTRASONIC FLOWMETERS

G. I. Birger

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An important sphere of application of ultrasonic flowmeters consists in checking the flow of corrosive liquids and pulp where it is impossible to use similar instruments and methods of measurement. However, nearly all the ultrasonic flowmeters described in literature [1-12] are intended for measuring the speed of flow in pure noncorrosive liquids (water, oil products, etc.). At the same time in the works published to date on this subject only a simplified theoretical treatment of ultrasonic flowmeters is given, without analyzing the errors, thus making it difficult to choose the most suitable type in the construction and layout of flowmeters for given measuring conditions and properties of the measured medium. Therefore, a pressing necessity has arisen for developing the foundations of an ultrasonic flowmeter theory with their classification and an analysis of their errors.

Classification of ultrasonic flowmeters. It is known that the principle of operation of ultrasonic flowmeters is based on the fact that the speed of propagation of ultrasonic vibrations in a moving medium with respect to a system of stationary coordinates (the walls of a pipe) is equal to the vector sum of the supersonic velocity with respect to the medium and the velocity of the medium with respect to the pipe. Hence, if two piezoelectric crystal transducers are mounted for radiating ultrasonic vibrations in the direction of the flow and against it, and two ultrasonic receivers are placed at the same distance from their respective radiators, the signals in the two ultrasonic channels will arrive through the moving liquid at the receivers with a certain acoustical propagation difference, which will bear a single-valued relationship to the speed of the liquid flow.

The measurement of the acoustical propagation difference is normally reduced by various methods the difference in the propagation time of the ultrasonic vibrations with and against the liquid flow: 1) by a direct measurement of the ultrasonic pulses propagation time; 2) by measuring the phase difference in the ultrasonic vibrations propagated with and against the liquid flow in a state of continuous radiation, and 3) by measuring the difference in the repetition frequency of spaces or ultrasonic pulses propagated with and against the flow, in such a manner that each succeeding space or pulse is produced by the preceding one received by the piezoelectric element. Preliminary calculations have shown that the direct measurement of the ultrasonic pulse propagation time requires an excessively high degree of accuracy. Hence, we shall refrain from examining this method any further. Neither shall we examine the method of measuring directly the geometrical displacement of the ultrasonic beam by the liquid flow [7], since this method is only suitable for pure liquids over a narrow velocity range.

In addition to classifying the ultrasonic flowmeters by their measuring circuits, it is also necessary to divide them according to the types of their transducers, which are selected to suit their production operation requirements. Among other things it is necessary to protect the surface of piezoelectric elements in measuring corrosive liquids and pulps by sound-conducting layers whose parameters must be allowed for in computations. Moreover, in checking the flow of contaminated liquids and pulps the presence of any "pockets" or protruding parts cannot be tolerated on the surface of the transducers. Hence, in certain transducers the ultrasonic beam will strike the surface between the sound receiver and the liquid at an angle and will be refracted at the surface.

Two basic types of transducers are possible, with or without refraction. A transducer in which the angle between the axis of the pipe and the direction of ultrasonic propagation in the measured liquid does not depend on its acoustical properties is known as a transducer without refraction. A transducer in which this direction depends on the acoustical properties is known as a transducer with refraction. One of the versions of transducers without refraction is shown schematically in Fig. 1, and that with refraction in Fig. 2.

Thus, in conjunction with the three basic types of measuring circuits (phase, spaced frequency and pulsed frequency) it is possible to distinguish six basic types of ultrasonic flowmeters. Various modifications of these types as, for instance, a phase method with modulation [3, 8] do not interfere with the above classification and can be analyzed within the framework of the relations given below, or by means of similar methods.

Basic relationships of the theory. The ultrasonic velocity of propagation in the measured medium and the acoustic lines is approximately three times greater than the flow velocity of the liquid in the pipe; hence, even relatively small ultrasonic velocity variations due to temperature may, under certain conditions, produce errors which are comparable to the measured flow, or may even exceed it. In this connection the analysis of possible errors in ultrasonic flowmeters and the means for avoiding them by specifying certain accuracy requirements in the manufacture of transducer components is of decisive importance in the design of the instrument as a whole.

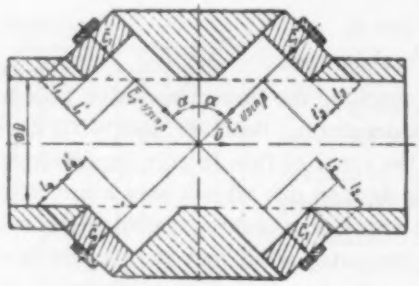

Fig. 1 .

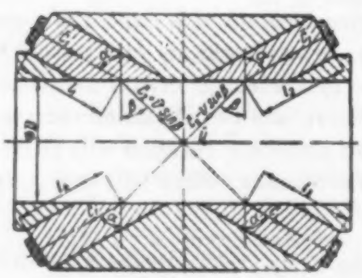

Fig. 2 .

In existing literature an analytical examination is provided only for phase and spaced-frequency circuits using transducers without refraction, on the assumption that both electronic-acoustical channels are completely symmetrical and the parameters of these channels do not vary during the operation of the instrument. However, the parameters of the two channels cannot be made identical with a sufficient accuracy (omitting the commutated single-channel circuits, which have their own peculiarities and difficulties). Thus, in computing all the types of ultrasonic flowmeters it becomes necessary to account for the asymmetry of parameters in the electronic-acoustical channels.

The initial reading of the flowmeters due to the asymmetry of channels may be compensated one way or another. However, as will be shown later, the presence even of compensated asymmetry in transducer channels produces errors due to variations (on account of temperature or composition differences) in the ultrasonic velocity of the tested medium and of the acoustical lines.

Thus, in addition to normal errors due to uncontrolled variation in the parameters of the transducer and the electronic circuit, which we shall denote by $\delta$, the ultrasonic flowmeters also have errors due to the presence of the compensated asymmetry of electronic-acoustical channel parameters, which we shall denote by $\delta_0$.

In deriving complete formulas for all the types of ultrasonic flowmeters we shall account for the asymmetry of the following transducer parameters: the thickness of the diaphragm or the corresponding length of acoustical lines $\delta_0 l$; angles between the direction of ultrasonic "rays" and the pipe axis $\delta_0\alpha$; the pipe diameter (ellipticity of the cross section) $\delta_0 D$. Moreover, other quantities characteristic for some of the flowmeter types will also be taken into consideration. A detailed analysis of the effect of asymmetry and variations in parameters of electronic channels will not be undertaken.

In all the cases it is assumed that the beam of ultrasonic oscillations is transmitted without spreading out, and hence it is possible to consider only one central ultrasonic "ray."

Phase circuit using a transducer without refraction. Continuous ultrasonic oscillations induced in the radiating piezoelectric elements by a common generator are fed to the measured medium through plane-parallel diaphragms in the direction of the flow in one channel and against it in the other. The ultrasonic oscillations reach the receiving piezoelectric elements in the two channels with a certain phase difference $\Delta\varphi$. After the amplification and limitation in the two separate channels they are fed to a phase detector, which provides a dc voltage proportional to the phase difference and hence to the velocity of the flow. The phase difference due to the asymmetry of the acoustical and electronic channels may be compensated by means of a phase shifter.

The comprehensive formula for flowmeters of this type, after the elimination of small terms, can be represented by the following expression:

$$\Delta\varphi = \omega\left(\frac{2Dv\tan\alpha}{c_2^2} + \frac{\delta_0 l}{c_1} + \frac{\delta_0 l'}{c_2} + \frac{D\sin\alpha}{c_2\cos^2\alpha}\delta_0\alpha + \frac{\delta_0 D}{c_2\cos\alpha}\right) + \delta\varphi_e .$$

where $\Delta\varphi$ is the phase difference in ultrasonic oscillations received in the transducer channels; $\omega$ is the angular velocity of ultrasonic oscillations; $c_1$ is the ultrasonic velocity of the sound-conducting diaphragms; $c_2$ is the ultrasonic velocity in the measured liquid; $\underline{v}$ is the mean velocity of the liquid flow in the pipe; $\alpha$ is the angle between the ultrasonic ray and a perpendicular to the pipe axis; $l$ is the thickness of the sound-conducting diaphragms; $l'$ is the depth of "pockets" in the direction of the acoustical channel axis; D is the pipe diameter; $\delta\varphi_e$ is the uncontrolled phase difference in the electronic circuit of the instrument.

The first term in the bracket represents the phase shift due to the propagation of liquid in the pipe, and the remaining terms those due to the asymmetry of various transducer parameters. The value of all these terms depends on the ultrasonic velocity whose variations will produce corresponding errors.

The ultrasonic velocity of the tested medium depends on its composition and temperature, but in the acoustical lines only on temperature. For small variations in temperature and concentrations in the liquid it is possible to assume a linear relationship of the ultrasonic velocity to temperature and concentration:

$$\begin{aligned} c_1 &= c_{1_0}(1+\gamma_1 t); \\ c_2 &= c_{2_0}(1+\gamma_2 t+\beta_2 q); \\ n &= \frac{c_2}{c_1} \simeq n_0(1+\gamma_3 t+\beta_2 q), \end{aligned} \tag{2}$$

where

$$n_0=\frac{c_{2_0}}{c_{1_0}}, \qquad \gamma_3=\gamma_2-\gamma_1,$$

$\underline{q}$ is the total referred concentration of the components in the solution;

Taking into consideration the errors due both to the uncompensated variations in the transducer parameters, of the electronic circuit and the tested medium, and to the asymmetry of their values, the quadratic mean error in measuring the phase difference can be represented by the expression:

$$\delta\varphi=\sqrt{(\delta\varphi_t)^2+(\delta\varphi_q)^2+(\delta\varphi_l)^2+(\delta\varphi_{l'})^2+(\delta\varphi_\alpha)^2+(\delta\varphi_D)^2+(\delta\varphi_e)^2}, \tag{3}$$

where

$$\delta\varphi_t=\frac{\partial\Delta\varphi}{\partial t}\,\delta t=-\omega\left(\frac{4\gamma_2 Dv\tan\alpha}{c_2^2}+\frac{\gamma_1}{c_1}\delta_0 l+\right.$$

$$\left.+\frac{\gamma_2}{c_2}\delta_0 l'+\frac{\gamma_2 D\sin\alpha}{c_2\cos^2\alpha}\delta_0\alpha+\frac{\gamma_2}{c_2\cos\alpha}\delta_0 D\right)\delta t;$$

$$\delta\varphi_q=\frac{\partial\Delta\varphi}{\partial q}\,\delta q-\frac{4\omega\beta_2 Dv\tan\alpha}{c_2^2}\,\delta q;$$

$$\delta\varphi_l=\frac{\omega}{c_1}\,\delta l;$$

$$\delta\varphi_{l'}=\frac{\omega}{c_2}\,\delta l';$$

$$\delta\varphi_\alpha=\frac{\omega D\sin\alpha}{c_2\cos^2\alpha}\,\delta\alpha;$$

$$\delta\varphi_D=\frac{\omega}{c_2\cos\alpha}\,\delta D.$$

By setting a definite value for the maximum error and using (3) it is possible to calculate the accuracy requirements for maintaining the parameters of the tested medium for the manufacture of transducer elements as well as the permissible deviations in the transducer parameters during operation.

<u>Pulsed frequency and spaced frequency circuits for transducers without refractions.</u> In the pulsed frequency circuit the radiating piezoelectric element of each transducer channel receives a short high-frequency electric pulse from

its generator. Each pulse is transmitted through the tested medium to its receiving piezoelectric element, and after transformation causes the next operation of its generator.

In the spaced frequency circuit the radiating piezoelectric elements of both channels are fed with continuous electrical high-frequency oscillations from separate generators. The signals received by the piezoelectric elements block after transformation their respective generators. As soon as the signals stop being received by the piezoelectric elements the generators are again unblocked and the entire cycle is repeated.

Thus in each channel a series of ultrasonic pulses or spaces is produced with different repetition frequencies. The difference in the repetition frequency $\Delta F$ of pulses or spaces in both channels is in the main determined by the velocity of the tested liquid in the pipe.

A comprehensive formula for the flowmeter operating with a pulsed frequency circuit is

$$\Delta F = \frac{\sin 2\alpha \left[ v + \frac{c_2}{2 \sin \alpha} \left( \frac{n \cos \alpha}{D} \delta_0 l + \frac{\cos \alpha}{D} \delta_0 l' + \tan\alpha \delta_0 \alpha + \frac{\delta_0 D}{D} \right) + \frac{c_2^2 \text{ st } \alpha}{D} (\delta_0 \tau + \delta \tau) \right]}{D \left( 1 + \frac{nl + l' + c_2 \tau}{D} \cos \alpha \right)^2}, \tag{4}$$

where $\tau$ is the constant component of the pulse delay time in both electronic-acoustical channels; $\delta_0 \tau$ is the asymmetry in the delay time; $\delta \tau$ is the variation in the delay time in the electronic-acoustical channels.

The comprehensive formula for a flowmeter with a spaced frequency circuit is similar to (4) only differing by the factor of 0.5.

The numerator of (4) consists of three terms, the first of which represents the velocity of the tested liquid flow, the second the asymmetry of the transducer parameters, and the third the asymmetry of the electronic circuit parameters.

Only when electronic-acoustical channels are completely symmetrical, when there is no delay of signals in them, and the effect of acoustic line diaphragms and "pockets" is neglected, does it become possible to obtain the greatly simplified well-known relationship for the pulsed frequency circuit.

$$\Delta F = \frac{\sin 2\alpha}{D} v \tag{5}$$

and for the spaced frequency circuit

$$\Delta F = \frac{\sin 2\alpha}{2D} v. \tag{6}$$

In these relations the difference frequency does not depend on the ultrasonic speed in the tested medium, thus eliminating any temperature errors. However, ultrasonic speed is included in the comprehensive expressions and, hence, certain temperature errors are characteristic of pulsed frequency and spaced frequency circuits.

The quadratic mean error in measuring the difference frequency can be represented in a manner similar to (3) by the expression:

$$\delta F = \sqrt{(\delta F_t)^2 + (\delta F_q)^2 + (\delta F_l)^2 + (\delta F_{l'})^2 + (\delta F_\alpha)^2 + (\delta F_D)^2 + (\delta F_\tau)^2 + (\delta F_e)^2}. \tag{7}$$

Expressions for the terms under the radical which can be calculated in a manner similar to that used in (3) are not given here, since some of them are very cumbersome.

It is only necessary to examine the expression $\delta F_t = \frac{\partial \Delta F}{\partial t} \delta t$ for the purely temperature error, i. e., in the absence of asymmetry or lagging

$$\frac{\partial \Delta F}{\partial t} = \frac{2v \sin 2\alpha (\gamma_1 n_0 l + \gamma_2 c_{2_0} \tau) \cos \alpha}{D^2 \left( 1 + \frac{n_0 l + l' + c_{2_0} \tau}{D} \cos \alpha \right)^3}. \tag{8}$$

It will be seen from (8) that the temperature error becomes equal to zero if the following condition is observed:

$$\gamma_2 = \frac{n_0 l}{n_0 l + c_{2_0} \tau} \gamma_1. \tag{9}$$

The above expression is a condition for the compensation of purely temperature errors.

Phase circuit with reflections. Let us now examine a version of the phase circuit with refractions in which the sound-conducting rods are mounted flush with the internal surface of the pipe. In other respects this circuit is identical to the phase circuit without refractions.

A comprehensive formula for the above type of ultrasonic flowmeter has the form:

$$\Delta\varphi = \omega\left[\frac{2Dv \sin\alpha}{c_1 c_2 \sqrt{1-n^2\sin^2\alpha}} + \frac{\delta_0 l}{c_1} + \frac{nD\sin 2\alpha\,\Delta_0\alpha}{2c_1\sqrt{(1-n^2\sin^2\alpha)^3}} + \frac{\Delta_0 D}{c_2\sqrt{1-n^2\sin^2\alpha}}\right] + \delta\varphi_e \tag{10}$$

where $\alpha$ is the angle between the acoustic line axis and the perpendicular to the pipe axis.

The expression for the quadratic mean error in this case is similar to that in (3) and (7):

$$\delta\varphi = \sqrt{(\delta\varphi_t)^2 + (\delta\varphi_q)^2 + (\delta\varphi_l)^2 + (\delta\varphi_\alpha)^2 + (\delta\varphi_D)^2 + (\delta\varphi_e)^2}\,. \tag{11}$$

where

$$\delta\varphi_t = \frac{\partial\Delta\varphi}{\partial t}\,\delta t =$$

$$= -\omega\left\{\frac{2Dv\,[\gamma_1 + \gamma_2\,(1-2n_0^2\sin^2\alpha)]\sin\alpha}{c_{1_0}\,c_{2_0}\sqrt{(1-n_0^2\sin^2\alpha)^3}} + \frac{\gamma_1}{c_{1_0}}\,\delta_0 l + \right.$$

$$+ \frac{D\,[(\gamma_2-\gamma_1)(1-n_0^2\sin^2\alpha) + 3\gamma_3 n_0^2\sin^2\alpha]\sin 2\alpha}{2c_{1_0}\sqrt{(1-n_0^2\sin^2\alpha)^5}}\,\delta_0\alpha +$$

$$\left. + \frac{\gamma_2 - (\gamma_2+\gamma_3)\,n_0^2\sin^2\alpha}{c_{2_0}\sqrt{(1-n_0^2\sin^2\alpha)^3}}\,\delta_0 D\right\}\delta t;$$

$$\delta\varphi_q = \frac{\partial\Delta\varphi}{\partial q}\,\delta q =$$

$$= -\frac{2\omega D v \beta_2\,(1-2n_0^2\sin^2\alpha)\sin\alpha}{c_{1_0}\,c_{2_0}\sqrt{(1-n_0^2\sin^2\alpha)^3}}\,\delta q;$$

$$\delta\varphi_l = \frac{\omega}{c_1}\,\delta l;$$

$$\delta\varphi_\alpha = \frac{\omega D_n \sin 2\alpha}{2c_1\sqrt{(1-n^2\sin^2\alpha)^3}}\,\delta\alpha;$$

$$\delta\varphi_D = \frac{\omega}{c_2\sqrt{1-n^2\sin^2\alpha}}\,\delta D.$$

The first term of expression $\partial\Delta\varphi/\partial t$ represents the purely temperature error. Let us find the value of the parameters for which this expression becomes zero:

$$\gamma_1 + \gamma_2\,(1-2n_0^2\sin^2\alpha) = 0. \tag{12}$$

The above expression determines the condition of temperature compensation for the transducer. The value of the $\sin\alpha$ from (12) can be expressed as:

$$\sin\alpha=\frac{1}{n_0}\sqrt{\frac{\gamma_1+\gamma_2}{2\gamma_2}}. \tag{13}$$

Thus, knowing the values of $c_2$ and $\gamma_2$ for the tested medium, it is possible, by selecting the acoustic line material with the required characteristics and appropriately calculating angle $\alpha$, to provide an automatic compensation of the purely temperature error of the transducer. In practice this can be easily provided for water and many aqueous solutions which have $\gamma_2 > 0$ in the range of operating temperatures.

Pulsed frequency and spaced frequency circuits with refractions. The comprehensive formula for pulsed frequency circuits with refractions has the following form:

$$\Delta F=\frac{2n\sqrt{1-n^2\sin^2\alpha}\sin\alpha\left\{v+\frac{c_1}{2\sin\alpha}\left[\frac{n\sqrt{1-n^2\sin^2\alpha}}{D}\delta_0 l+\frac{n^2\sin 2\alpha}{2(1-n^2\sin^2\alpha)}\delta_0\alpha+\frac{\delta_0 D}{D}\right]\right\}}{D\left(1+\frac{nl+c_2\tau}{D}\sqrt{1-n^2\sin^2\alpha}\right)^2}+$$
$$+\frac{2n\sqrt{1-n^2\sin^2\alpha}\sin\alpha\,\frac{c_1c_2\sqrt{1-n^2\sin^2\alpha}}{D\sin\alpha}(\delta_0\tau+\delta\tau)}{D\left(1+\frac{nl+c_2\tau}{D}\sqrt{1-n^2\sin^2\alpha}\right)^2} \tag{14}$$

The comprehensive formula for the spaced frequency circuit differs from (14) only by the absence of coefficient 2 in the numerator.

Providing the electronic-acoustical channels are completely symmetrical it is possible to obtain a simplified formula for the pulsed frequency and spaced frequency circuits, respectively:

$$\Delta F=\frac{2n\sqrt{1-n^2\sin^2\alpha}\,\sin\alpha}{D\left(1+\frac{nl+c_2\tau}{D}\sqrt{1-n^2\sin^2\alpha}\right)^2}v; \tag{15}$$

$$\Delta F=\frac{n\sqrt{1-n^2\sin^2\alpha}\,\sin\alpha}{D\left(1+\frac{nl+c_2\tau}{D}\sqrt{1-n^2\sin^2\alpha}\right)^2}v. \tag{16}$$

The general expression for the quadratic mean error in measuring the differnce frequency has a form similar to that given in (7) with the exception of the term depending on asymmetry and variation in the depth of "pockets."

In a manner similar to the phase circuit with refractions it is possible to obtain, from the expression for a purely temperature error, the condition of the transducer temperature compensations which, in this case, has the form

$$l=\frac{D}{n_0}\sqrt{\frac{2\gamma_2}{\gamma_2-\gamma_1}}; \tag{17}$$
$$\sin\alpha=\frac{1}{n_0}\sqrt{\frac{\gamma_1+\gamma_2}{2\gamma_2}}.$$

Thus, an automatic compensation of the transducer temperature error can be provided by selecting the required characteristics for the acoustic line material and appropriately calculating the length of the acoustic line.

Tables 1 and 2 show the maximum permissible asymmetry and uncompensated variations in the parameters of a transducer intended for measuring titanium tetrachloride pulp in a pipe with an internal diameter of 50 mm over a range of 0-80 $m^3$/hr. All the cited values were calculated with the assumption that the maximum errors from each source amounted to $\pm 1\%$ of the measurement range, and that the possible variations of the tested medium temperature did not exceed $\pm 10°C$.

TABLE 1. Maximum Permissible Asymmetry in Transducer Parameters

| Parameter | Phase circuit | | Pulsed frequency circuit | | Space frequency circuit | |
|---|---|---|---|---|---|---|
| | without refractions | with refractions | without refractions | with refractions | without refractions | with refractions |
| Diaphragm thickness or length of acoustic lines mm . . . . . . . . . . | 0.5 | 0.5 | 0.5 | 2.3 | 0.5 | 2.3 |
| Depth of pockets, mm . | 0.13 | — | 0.2 | — | 0.2 | — |
| Difference in angles . . | 17' | 1° | 13.5' | 1° | 13.5' | 1° |
| Ellipticity in pipe cross sections, mm . . . . . | 0.12 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 |
| Delay time of pulses, μ sec . . . . . . . . . . | — | — | 1 | — | 2 | — |

Comparative analysis of the basic types of ultrasonic flowmeters. An analysis of the above relationship makes it possible to determine the measurement ranges, advantages, defects, and the possible application of the basic types of ultrasonic flowmeters on the basis of the measuring conditions and the properties of the measured medium.

The phase curcuit using a transducer without refractions is characterized by a high sensistivity and can be used for measuring the instanteneous discharge of pulsating and rapidly changing flows of liquid. The analysis of errors has shown that this circuit is characterized by relatively small temperature errors as compared with all the other types of ultrasonic flowmeters. However, this circuit imposes very strict requirements on asymmetry and uncompensated transducer parameter variations.

TABLE 2. Maximum Permissible Uncompensated Parameter Variations in the Transducer and the Electronic-Acoustical Channels.

| Parameter | Phase circuit | | Pulsed frequency circuit | | Space frequency circuit | |
|---|---|---|---|---|---|---|
| | without refractions | with refractions | without refractions | with refractions | without refractions | with refractions |
| Tested medium temperature, °C . . . . . . . . | 4 | 5.5 | >10 | >10 | >10 | >10 |
| Ultrasonic velocity in the tested medium, % . . . | 1 | 2.5 | >10 | >10 | >10 | >10 |
| Difference in the thickness of diaphragms or in the length of acoustic lines, mm . . . . . . . | 0.008 | 0.008 | 0.12 | 0.01 | 0.12 | 0.01 |
| Difference in the depth of pockets, mm . . . . . | 0.003 | — | 0.052 | — | 0.052 | — |
| Difference in angles . . . | 25" | 3.2' | 22" | 2' | 22" | 2' |
| Ellipticity in the cross section of pipes, mm . . . | 0.003 | 0.003 | 0.015 | 0.004 | 0.015 | 0.004 |
| Difference in the delay time of pulses, μsec. . | — | — | 0.05 | 0.005 | 0.1 | 0.1 |

The pulsed frequency and spaced frequency circuits using transducers without refractions are highly sensitive only for small pipe diameters. Contrary to the phase circuit all the frequency circuits have a large time constant.

The error analysis shows that in flowmeters of this type purely temperature errors are practically absent, which is of considerable advantage. However, these circuits also impose very strict requirements with respect to asymmetry, uncompensated transducer parameter variations, uncompensated pulse time delays, and corresponding differences in the variations of electronic-acoustical channel parameters. The latter requirement can only be met by considerably raising the operating frequency, thus limiting the sphere of application of these flowmeters to media with a small absorption of high-frequency ultrasonic vibrations.

The sensitivity of the phase circuit with refractions is only a fraction of that without refractions; however, in the range of medium and large flows (tens and hundreds of cubic meters per hour) the sensitivity of this circuit is satisfactory. One of the essential advantages of this circuit consists in the possibility of an automatic compensation of the transducer temperature errors without affecting the internal cross section of the pipe, thus making it possible to use the circuit for measuring the flow of pulps, crystallizing and polluted liquids. The requirements for asymmetry and uncompensated transducer parameter variations are considerably less strict for this circuit than for the phase circuit without refractions.

The pulsed frequency and spaced frequency circuits with refractions have a considerably smaller sensitivity as compared with the circuits already mentioned, and can therefore only be used with small diameter pipes (up to about 50 mm). The error analysis shows that both these circuits impose practically unattainable requirements with respect to the variations in the pulse delay time and hence, in the paramenters of the electronic-acoustical channels.

It is possible to conclude from the above that it is most expedient to use the following basic types of ultrasonic flowmeters: the phase type with and without refractions, and the pulsed frequency types without refractions.

Table 3 shows the optimum circuits of ultrasonic flowmeters for various measurement ranges and characteristics of the measured medium.

TABLE 3

| Circuit | Approximate measuring ranges, $m^3/hr$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | pure liquids | | | | polluted liquids | | | |
| | <1 | 1-10 | 10-100 | >100 | <1 | 1-10 | 10-100 | >100 |
| Phase without refractions | ++ | + | + | + | – | – | – | – |
| Pulsed frequency without refractions | + | ++ | ++ | + | – | – | – | – |
| Spaced frequency without refractions | – | + | + | – | – | – | – | – |
| Phase with refractions | + | + | ++ | ++ | + | ++ | ++ | + |
| Frequency with refractions | – | – | – | – | – | – | – | – |

Note: Sign "++" denotes preferred circuits.

On the basis of the above general theoretical propositions the "Tsvetavtomatika" Design Bureau has developed an ultrasonic flowmeter type RUZ-282 for checking the flow of titanium tetrachloride pulp. The experimental model of this instrument has passed its production test satisfactorily.

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# ESSAYS AND REVIEWS

## NEW DIGITAL INSTRUMENTS

F. A. Sorokin

Translated from Izmeritel'naya Tekhnika, No. 4,
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The present-day level of technical development imposes more exacting requirements on monitoring and control instruments, and in particular with respect to their speed of operation and reliability of reading.

A tendency is therefore developing in instrument-making of changing over from pointer to digital instruments which have several advantages: great accuracy at high speed of measurement, increased readout speed without the possibility of reading errors, "self-checking" facilities, the possiblitity of remote transmission without loss of accuracy, the provision of results in a form suitable for further processing in computers, and the possibility of automatic storing (memory) of measurement results.

Complete automation by means of computers is impossible without digital instruments.

The principle of operation of digital instruments consists in converting the measured quantity or its analogue (i. e., a physical quantity proportional to that measured, for instance, in measuring temperature the emf of a thermocouple of the value of a resistance thermometer) into a digital code which is then used in an indicating, recording or controlling device.

Digital codes consist of various counting systems which differ from each other by their base, i. e., the number which forms units on the second and subsequent orders. Thus, in one of the most common systems, the binary number 2 is used as a base and each succeeding order is twice as large as the preceding one.

The disadvantage of the binary system is the necessity for its conversion into a decimal system, which is normally used outside the instrument application. This has led to the extensive use of a combined binary-decimal system, which incorporates the advantages of both systems. Number 10 serves as the base of this system, but each figure is represented by its binary equivalent (see Table).

Table 1

| Order | 1000 | | | | 100 | | | | 10 | | | | 1 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Figure | $2^3=8$ | $2^2=4$ | $2^1=2$ | $2^0=1$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ |
| Operation of circuit element | | | | × | | | × | | × | | | × | | | | × |
| Representation | 0001001010010001 | | | | | | | | | | | | | | | |
| Calculation of value | $2^0 \cdot 1000 + 2^1 \cdot 100 + 2^3 \cdot 10 + 2^0 \cdot 10 + 2^0 \cdot 1 = 1291$ | | | | | | | | | | | | | | | |

The coded number is as a rule represented by "binary" elements. In this case the attribute which determines the value of the quantity consists of the presence or absence of a pulse irrespective of its amplitude, which can be varied in transmission or conversion. The representation is therefore restricted to two symbols : 1 and 0.

Circuit elements for "binary" coding may consist of electromagnetic relays (operated, released), electron tubes and transistors (conducting, blocked), and magnets (energized positively).

In pointer indicating instruments a loss of the initial accuracy is inevitable when transmitting or processing analogue quantities (summing, multiplying, differentiating, storing, etc.). Errors accumulate without the possibility of

estimating or correcting them. When digital methods are used such a loss of accuracy is eliminated by the very nature of the presentation of measurement results. An error can only arise in two extreme cases, namely, the loss of a transmitted pulse or the appearance of a stray interference pulse. This leads to a pronounced change in the transmitted number. Such digital instrument errors can be eliminated fairly easily by means of a self-checking unit. The principle of self-checking operation consists of the following. The coded number contains, in addition to the basic elements required for representing the figure, also auxiliary checking which form with the basic elements a definite combination for a given code, for instance, the number of symbols 1 must be odd. A failure in this combination indicates the error, which can than be eliminated or corrected.

The output of a digital instrument can be connected directly to the input of a computer or a discrete control system, which is particularly important, in the case of multiple monitoring.

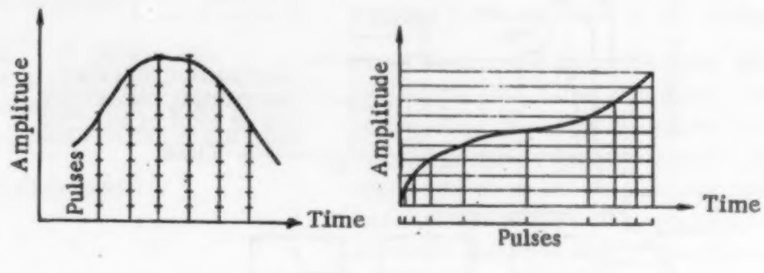


Fig. 1.

Digital instruments can be used both for measuring instantaneous values and as integrators. In the latter case the analogue variable which is characterized by its amplitude is divided into separate parts equal in their effect (quanta) which are then represented by means of pulses. The principle of operation of these two types of digital instruments is illustrated by graphs in Fig. 1a, showing the conversion into a discrete form of instantaneous values of the measured variable, and Fig. 1b, showing the conversion into a discrete form of equal amplitude increments.

Analogue-to-digital converter (digitizer). A digital instrument's input signal can consist of a voltage (current) or a rotation angle. In the first case the conversion of the input signal into a discrete form is carried out in the following manner.

1. The measured voltage is compared with a reference voltage obtained from a sawtooth generator (Fig. 2). The value of the voltage ramp corresponding to zero and the measured voltage limit the time interval proportional to the measured voltage. This interval is evaluated in terms of standard pulses which serve to represent the input voltage in a discrete form. The conversion error is determined by the linearity of the voltage ramp, the constancy of the pulse generator frequency, and the zero drift in the comparator unit. Such a converter can provide an error not exceeding ± 2% with a conversion cycle of 20 msec when measuring voltages of the order of 10 v.

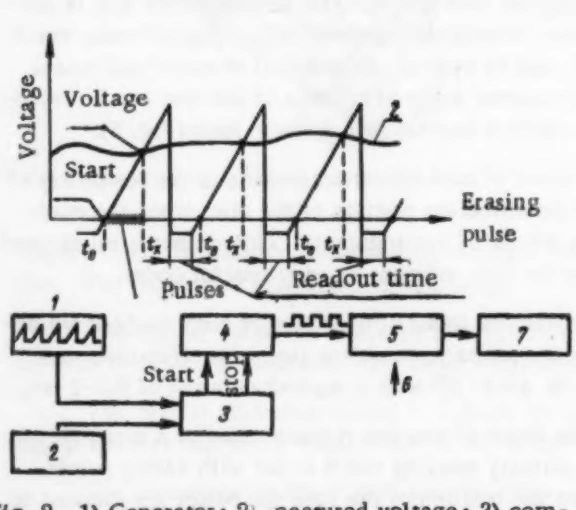


Fig. 2. 1) Generator; 2) measured voltage; 3) comparator unit; 4) pulse generator; 5) digitizer; 6) erasing pulse; 7) indicator (v).

Another version of such a converter uses reference pulses for evaluating the time interval produced by a discharge of a capacitor which is charged by the measured voltage.

2. The measured voltage is compared with the reference voltage whose value is changed in steps by means of a relay. The pulse for switching in the next relay can be provided by the difference between the measured voltage and that of the preceding step. The step for which the reference voltage becomes larger than the measured voltage is disconnected after comparison. The steps which provide a reference voltage value smaller or equal to the measured voltage remain connected. The combination of the remaining voltage steps provide the digital code. Figure 3 shows the schematic of the converter and a specific example showing the representation of number 45 in the digital code.

The conversion error is determined by the error of reference resistors which provide the voltage steps, the stability of the reference current source, and the zero drift of the comparison unit. It can be made smaller than ± 0.05% for three convertions per second.

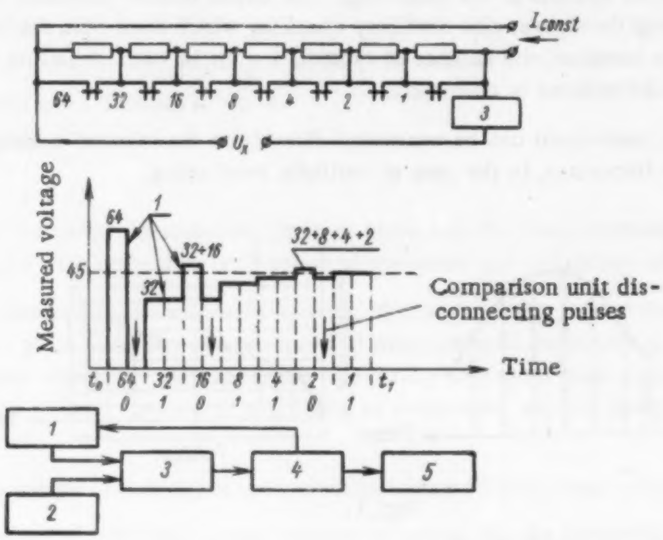


Fig. 3. 1) Reference voltage; 2) measured voltage; 3) comparison unit; 4) digitizer; 5) indicator (v).

A converter of this type is the only one which can operate in a "self-excitation" condition when the input voltage is continuously compared with its last coded value. As soon as the voltage changes the new conversion process is originated automatically. The "self-excitation" can be set only in one direction, i. e., the instrument will register either the maximum or minimum values of the measured voltage.

3. The voltage is converted by means of a miniature motor into a strictly proportional number of revolutions and then into a proportional number of pulses by means of an interrupter. Such a design is often used for digital integrators (Fig. 4). Such converters provide at their output 0.008 to 480 pulses per minute, depending on the measurement range.

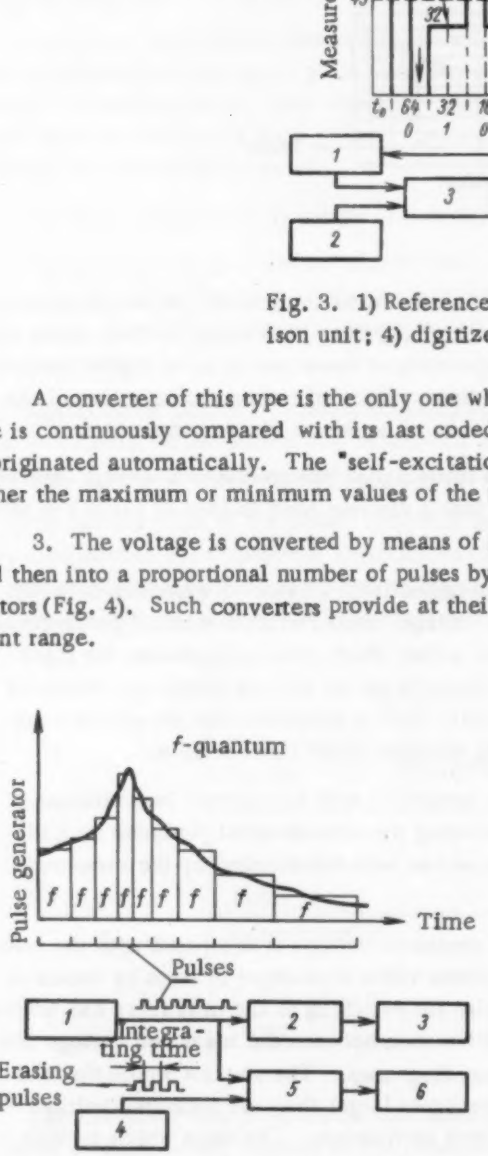


Fig. 4. 1) Pulse generator; 2) digitozer; 3) indicator (quantity); 4) pulse clock; 5) digitizer; 6) indicator (quantity/time).

In the second case, when the input signal consists of an angle of rotation the conversion is carried out in the following manner: 1) the axis of the measuring device is rigidly fixed to that of the digital coding disc. The surface of the disc is covered by means of separate segments with a digital code which can then be read by optical, mechanical or electrical means. Thus, every required angle of rotation of the disc can be represented by a definite number in a discrete form (Fig. 5).

The defect of such converters consists in the possibility of errors in an intermediate position of the disc, when the readout is on the border of two segments. This defect is eliminated by clamping the disc positions or using special codes.

The errors and speed of operation of such devices are determined by the primary measuring instruments (transducers) and amount to ±0.6 - 2% with a readout duration of 0.5-2 sec.

2. The angle of rotation is transmitted to a rotating core with a primary winding which is fed with dating pulses. Depending on the position of the core the pulses are induced in a different number of stationary secondary windings placed

along the circumference of the core. The combination of pulses induced in the excited secondary windings provides a digital code corresponding to the rotation angle of the core.

Digital display instruments (indicators). The following four types of digital indicators are used: 1) an optical system consisting of separate miniature electrical lamps and condensing lenses. Each lamp or corresponding lens is marked with a figure. According to the digital code fed to the indicator a definite lamp or combination of lamps is lighted, and the image of a figure or figures is projected onto a screen. In a similar way the screen can be lighted in different colors. The arrangement of such an indicator is shown in Fig. 6.

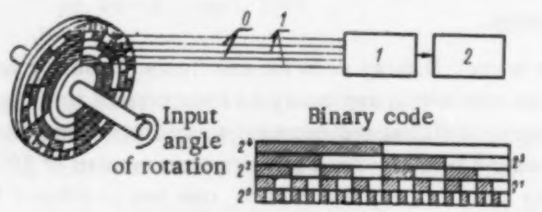


Fig. 5. 1) Digitizer; 2) indicator.

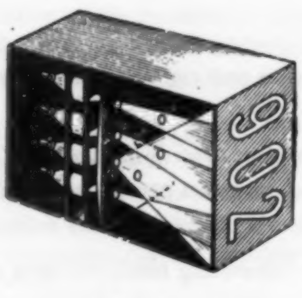

Fig. 6.

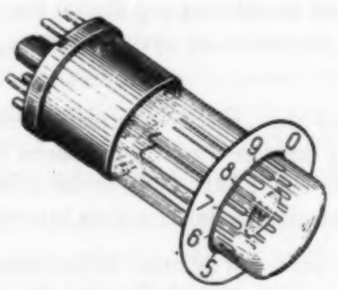

Fig. 7.

2. A set of thin perspex plates with engraved figures. Each plate can be lighted from the side by a separate lamp, thus making a definite figure visible. In operation the lamps corresponding to the digital code are lighted.

3. A system for decatrones, gas-discharge counting tubes, which consist of a disc anode and wire cathodes placed round it in a circle. The input pulses are fed to the wire cathodes in a certain sequence depending on the digital code. This produces a glow discharge between the appropriate cathode pin and the anode. Viewed from its end such a tube looks like a dial with a luminous drift indicator. The appearance of the tube with an attached scale is shown in Fig. 7.

4. A system of nodistrons, new gas-discharge tubes. The electrodes of the tube are placed one behind the other in a colimn made in the shape of figures. When a voltage is applied to the required electrode it lights up, providing a bright image of the figure.

Types of digital instruments. The most common digital instruments consist at present of voltmeters.

The new five-digit Solarton Electronic Group voltmeter model TM 923 has a range of 0.01-159.99 v and an error of 0.02%. It has an indicator with a digital projection on a screen. The polarity of the measured voltage is indicated by the coloring of the screen. The instrument can operate in a periodic readout condition or with indications preserving the previous reading until the instant of the new readout. The sensitivity of the instrument can be adjusted.

A four-digit voltmeter model LM902 of the same firm has 5 ranges: 0-0.1599, 0-1.599, 0-15.99, 0-159.9, and 0-1599v, with an error of 0.1% and a readout time of 280 m sec.

A five-digit voltmeter is made by the Blackburn Electronics Company. It has an error of 0.01% and provides up to three readouts per second. The time of one readout cycle can be adjusted between 13 and 103 msec. The instrument uses a digital display tube. In addition to measuring voltages the instrument can be used for measuring the ratio between quantities. The ranges are switched automatically.

The digital voltmeter made by the firm Nash and Thompson has four ranges: 0-1, 0-10, 0-100, 0-1000 v, with an error of ±1%. It consists of two units, a converter and a digital indicator.

The digital voltmeter model V-1 made by the Scientific Furnishing Company, is based on a stroboscopic principle, has five ranges: 0-0.25, 0-2.5, 0-25, 0-250 and 0.2500 v with an error of ±0.5%. Its readout time is 33 msec.

The instrument is fitted with a controllable damping which makes it insensitive to sharp peak and pulse interference. In addition to a periodic readout condition it can also operate in a condition when the digits pass in front of the screen, which is convenient for interpolation.

Digital instruments have also been designed for other measurements.

A six-digit type SA21A instrument for frequency measurements made by the Racal Instruments Company for a range of 10 cps - 1 Mc incorporates a reference frequency oscillator, has an intermediate memory device and can be coupled to a printer. The instrument is transistorized, has printed circuits and is insensitive to variations in the voltage or frequency of the supply. Its power consumption is 45 w (it can be supplied both from an ac and dc source).

A combined oscilloscope type 425 (Allen Du Mont) should be mentioned. It provides a digital display of points on an oscillogram in two coordinates, amplitude and time. It covers a range of 0-60 Mc. It has a screen of 100 x 50 mm. The instrument can be connected to a printing device. The instrument is assembled in five easily exchangeable units, thus making it possible to change its application and range.

The work for the unification of digital instruments should be noted. Display units for one figure (Counting Instruments Company) have been developed and consist of a complete unit which can easily be incorporated in a digital instrument used for any purpose. Such units can be used for making-up a digital indicator for an unlimited number of figures. The unit uses the optical projection method of figures onto a screen. The optical system consists of 12 miniature lamps and 12 lenses. The lenses are marked with figures from 0 to 9 and a comma, one lens is colored for illuminating the screen. The lenses can also be marked with letters and entire words. It is interesting to note the tendency to increase the area of legibility of the display. Thus, the new digital unit series 80000 provides an image of a figure of 94 x 50 mm, which can easily be read from a distance of 30 m, whereas a similar unit series 600 of an earlier design had figures measuring 25 x 16 mm.

A universal digitizer has been developed (Bristol Aircraft Co.), which provides an accuracy of 0.5% with a readout time of 3 msec. The digitizer provides at its output an 8-figure number and can be used with various transducers and indicating instruments.

Miniature analogue-to-digital and digital-to-analogue converters (Armstrong Whitworth Aircraft Company) intended for high-speed operation, provides 50,000 conversions per second. The converters operate with 8-figure numbers. The inverters provide a voltage at their output.

A microconverter (Nash and Thompson Company) has been designed for converting small voltages up to 1 v into a digital code.

Complex digital devices for multiple monitoring are being produced. An equipment of this type has been developed by the Radiatron Company for automatically checking the operation of a plant. The equipment provides a visual indication and recording of the measured overall consumption of a plant (of electricity, fuel, gas , steam, compressed air, oil, etc.). It is built up of standardized transducers and digital transducers and digital display units, and has a computer memory device in case of the mains voltage failure. A programming device provides a periodic recording of results in certain or all measurement channels.

In addition to the devices with visual digital displays, there are systems with acoustical outputs. One such system has a memory device. The measurement results are provided on calling the object over a telephone line. It is possible to transmit not only the value of the measured quantity at the instant of the call, but also the direction of its variation (increase or decrease), as well as its maximum or minimum value over a definite time interval.

Digital electrical measuring instruments for various purposes are being produced by other British firms (Lintronic Burndept Ltd., Ericsson Telephones, Ltd., British Physical Laboratories, etc.).

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# MATERIAL RECEIVED BY THE EDITORIAL BOARD

## WORKING EXPERIENCE OF A STATE INSPECTOR IN A RURAL DISTRICT*

L. Sh. Vinderman

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The supervision of measuring equipment in rural districts is one of the most important tasks performed by the GKL State Inspection Laboratories) according to instructions 12-58 of the Committee of Standards, Measures and Measuring Instruments attached to the Council of Ministers of the USSR.

In the Chernovitsy region this work is carried out by state inspectors who are allocated territories consisting, on an average, of four rural districts. The state inspector carries out in his district the state testing of measures and measuring instruments, supervises the checking of measures and measuring instruments at the plants carried out by the service and technical inspection agencies, checks the operation of the basic inspection agencies on his territory, controls the condition of the measuring equipment and its correct use, takes the necessary steps for introducing new measuring equipment in the plants and organizations, studies the operational characteristics of the measures and measuring instruments, and maintains contact with plants and organizations on problems affecting measurement equipment.

His activity is directed by the GKL through a yearly plan of work for rural districts, which consists of the following sections: the work of service and technical inspection teams in checking measures and measuring instruments; the work of instrument-repair teams; state checking of measures and measuring instruments; supervising the operation of the service and technical inspection; heavy inspection of measures and measuring instruments; checking the technique in measuring fuel and lubricating materials; and special on-the-spot inspection trips of the state inspector.

The plan provides for biannual on-the-spot inspection by the service and technical teams, their first trip being arranged 1-2 months before the state inspection of measures and measuring instruments, and the first trip of the instrument-repair teams 2-4 weeks before the state inspection date.

In addition to supervising the work of service and technical inspection agencies, each state inspector is provided with a plan for checking the condition of the oil products measuring equipment in 5-6 places. He also receives a schedule for his special trips to the establishments for rendering them assistance and inspecting their measuring equipment, taking into consideration the economy of the district, i. e., the seasonal operation of food plants, stocking operations, etc. Special attention is paid to his trips for inspecting the measuring equipment at automatic shops in sugar refineries and grain processing plants. The state inspection and testing of measures and measuring instruments is made by means of mobile laboratories installed on GAZ-51 motor trucks.

An important condition for maintianing the measuring equipment in a serviceable and efficient condition consists in a timely periodic checking of the measures and measuring instruments. In order to help the state inspectors in this work the Chernovitsy GKL has worked out a routine instruction for the heads of plants and a time-table for checking instruments. The existence of standard tables helps the state inspector to come to an agreement with the plants on the dates for checking their measuring equipment. In certain cases, when the regional organization or system includes similar establishments or plants with a small number of measures and measuring instruments used under the same conditions (regional health and agriculture departments, etc.) it has been found advisable to set the same dates for checking their instruments. In this instance each state inspector is supplied with a copy of the instruction to the administrator of the regional organization or system. However, it is impossible to set the same inspection dates for plants or organizations whose instruments operate under different conditions.

Simultaneously with setting the date for periodic inspection, the heads of organizations, establishments, plants, and collective farms appoint persons who are responsible for the state of the measuring equipment. The state inspector should see to ot that this responsible personnel remains stable, a frequent replacement of people in this position

*Some of the problems dealt with by the author repeat the propositions made in the article of V. D. Alesin (Measurement Techniques No. 10, 1960) .

complicates inspection work. It also important that all the problems affecting the measuring equipment should be discussed in the district Soviet Executive Committees, district militia departments, district Cooperatives and other district organizations, as well as by certain responsible people. The assistants thus provided for the state inspector should receive a required minimum of instructions in the maintenance of measuring equipment. The state inspector should, therefore, instruct this personnel at seminars, conferences and insist that the measures and measuring instruments be presented for state inspection by precisely these people and no-one else. The personal participation of the responsible people in the state testing of measures and measuring instruments is the best type of instruction. Thus they become acquainted with the technical requirements of the measuring equipment, and the technique of testing measures and measuring instruments. The state inspector together with the above personnel analyzes the reasons for defects in the equipment and makes the required recommendations to the plant on the maintenance of the equipment. The same personnel should also participate in the service and technical inspection at the plants. Heavy inspection of measures and measuring instruments should be carried out with the assistance of special personnel appointed by district organizations.

Another condition for maintaining the measuring equipment in an efficient state consists in a network of service maintanance and repair agencies. In the Chernovitsy region the measures and measuring instruments of the plants and establishments of all the departments are maintained and repaired in the rural districts by two area organizations, namely, the Chernovitsy regional agricultural departments located at the Sadgory RTS (Tractor repair station) and the Chernovitsy regional power administration of the Ukr. SSR Ministry of Agriculture. The laboratory of the regional agricultural administration maintains the instruments for mechanical, linear and thermotechnical measurements. It has at its disposal five mobile laboratories on specially equipped trucks. The laboratories have the right for compulsory checking of universal measuring instruments, manometers and milk measures used at the collective farms. The instruments are checked on the spot. In certain cases when the transportation of the testing equipment is impossible, the laboratory uses exchange instruments or separate parts, for instance, setting gauges for micrometers are checked at permanent laboratories on horizontal optimeters. The laboratory also repairs instruments for mechanical and thermotechnical instruments.

The Chernovitsy regional power administration maintains instruments for electrical measurements in all the rural districts of the region. It has three mobile laboratories at its disposal, installed on specially equipped trucks.

Thus, in all the rural districts the maintenance of measures and measuring instruments of all types by the service agencies is organized. The maintance agencies work to a plan which is slightly ahead of the on-the-spot inspection plan of the state inspector. This is necessary in order to enable the service and technical maintenance agencies to prepare the measures and measuring instruments for the forthcoming state inspection. The state inspector uses the trips of the service and technical agency personnel in order to maintain contact with the plants and at the same time entrusts them with the study of various aspects in the organization of measuring equipment in the establishments.

The existence of service and technical maintenance of measures and measuring instruments in rural districts greatly facilitates the work of the state inspector, since he is freed from checking a large number of instruments; to a considerable extent heavy inspection of the measuring equipment becomes unnecessary, the state inspection becomes easier, a constant maintenance of the measuring equipment in an efficient condition is provided, and more complete data on its condition obtained.

The most complicated part of the state inspector's work in rural districts consists in introducing new measuring equipment. Plants and organizations in the rural areas require, for many reasons, the assistance of the GKLs in choosing their new measuring equipment to a far greater extent than those in district centers. The state inspectors with their secondary technical education and experience mainly in the sphere of mechanical measurements, can introduce efficiently new measuring equipment only if constantly assisted by the GKL engineers specialized in various other spheres. The Chernovitsy GKL personnel have, therefore, made a special study of introducing new measuring techniques at certain plants in the most important branches of the region's economy. On the basis of this investigation and of the regional economy, the GKL personnel have worked out a memorandum for state inspectors. The memorandum includes a list of control and measuring instruments which can be introduced in the plants and establishments of the region, for each instrument and branches of the national economy in which it can be used, are shown, and its typical technical operating conditions indicated. The list of instruments in this memorandum is kept up-to-date as soon as data on new control and measuring instruments are received.

The study of the operational properties of measures and measuring instruments is carried out by the state inspectors both in urban and rural territories, thus accumulating extensive material on the operational advantages and disadvantages of many instruments.

The data presented by various state inspectors are compared, summarized and, if necessary, additional study of certain aspects is planned. Such a method of studying the operational properties of measures and measuring instruments, based on vast statistical material, is free from random errors and provides reliable results.

However, it should be noted that state inspectors working in rural districts are inadequately supplied with testing equipment. The lack, for instance, of a portable reference instrument for checking sphygmomanometers is completely unjustified; unequal arm balnce are checked by means of locally produced reference weights, since the production of reference grade 3 weights with radial slots has not been organized; the inspectors' reference portable scales for checking weights on the site at the plants and establishments are not efficient; a sufficiently convenient equipment for checking stationary scales is lacking; and the portable testing equipment for electrical and thermotechnical measuring instruments requires firther improvement.

The features by which the work of a state inspector in rural districts is judged should be radically changed. The principle of sectionalizing the work has been practiced for a long time in certain administrations of our country, therefore, it is quite correct to apply this principle to the system of the Committee of Standards, Measures and Measuring Instruments. However, the criterions for evaluating the inspectors' work should also have been changed. Normally a section head is judged by the size of his section and its efficiency. The section heads in the Committee's system, however, are not judged by the condition of the equipment in their district, but by the sum of payments received for testing instruments. Such a criterion has a most detrimental effect on the condition of the measurement equipment in the districts.

Moreover, the state inspector should be free from any unnecessary work in the district. For instance, he has to carry out a heavy inspection of measures and measuring instruments at 300-400 places per year, with 90% of the inspected objects passing the test. Yet, the state inspector is obliged to provide an inspection certificate for each object, irrespective of the test results. It seems to us that it is possible to dispense with official inspection certificates for those instruments which pass the tests, and it is sufficient to enter the test results in the state inspector's log book. If one considers that the writing out of an inspection certificate takes some 15 minutes, each state inspector will save per year about 12 working days, which can be used for more productive work.

We have described above the experience in a state inspector's work aimed at ensuring a uniform, accurate and correct use of measures and measuring instruments in our national economy. The elimination of the defects noted in this article will help achieve these aims.

## IT IS NECESSARY TO CHANGE THE DESIGN OF SLIDE GAUGES

B. P. Sakulin

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P. 56, April, 1961

The slide gauges in general use at the present time have a serious defect which, however, can be eliminated.

In measuring internal dimensions the gauge does not indicate the actual size. In order to obtain the actual size it is necessary to add to the measurement read off the vernier scale the width of the gauge jaws, which in the new gauges is equal to a whole number of millimeters, usually 10 or 9.

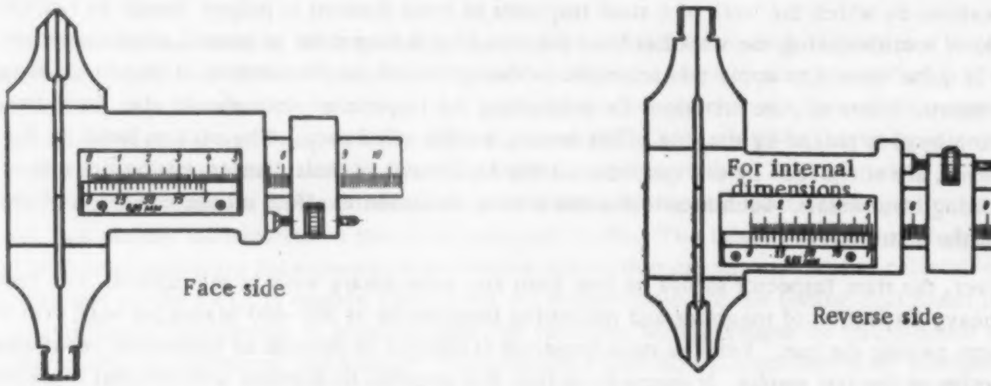
After a relatively small number of measurements the surface of the jaws used for internal measurements wears out and the size of the jaw width exceeds the tolerances of ±0.01, ±0.02, or ±0.03 mm, depending on the calibration of the vernier scale.

As soon as this wear is discovered the slide gauge is repaired, according to instruction 138-54, which permits the width of the jaws to be rounded off to tenths of a millimeter (9.9, 9.8 mm, etc.).

In many plants where the inspection of gauges is organized and they are being regularly repaired, the majority of slide gauges have jaw widths in fractions (every tenth) of a millimeter, such as 9.9, 9.8, 8.8 mm,etc.

Even if the jaw thickness is expressed in a whole number of millimeters the use of such a slide gauge for internal measurement is inconvenient. When this dimension is expressed in fractions of a millimeter the use of the gauge becomes almost impossible, since it is then necessary in measuring internal sizes to perform, usually mentally, complicated operations by adding to a fractional vernier reading the fractional size of the jaws. Very often even experienced workmen make mistakes in such calculations, which result in additional rejects in production.

In order to avoid this we suggest making slide gauges with a double scale. The face side should have a scale and vernier for external measurements, and the reverse side a second scale and vernier for internal (encompassed) measurements (see Figure).




Face side

Reverse side

On the second scale the zero calibration of the scale and the vernier should allow for the width of the jaws. The dimension read off the second scale will correspond to the actual internal dimension.

Repairs of a double-scale slide gauge do not worsen its operational properties, since the wear and decrease in the width of the measuring jaws can easily be compensated by resetting the vernier scale. The lapping of the measuring jaws during repairs also become easier. In the existing single-scale slide gauges it is necessary to lap the jaws during repairs very accurately to the nearest tenth of a millimeter, whereas this is not longer necessary in the case of double-scale gauges.

The operational advantages of a double-scale slide gauge are obvious and indisputable.

GOST (All-Union State Standard) 166-51 does not oblige but merely permits the manufacture of double-scale slide gauges.

The manufacturing plants should produce a sufficient number of double-scale gauges to satisfy the requirements of our national economy. The use of double-scale slide gauges will reduce the number of rejects and help to raise labor productivity.

# FROM THE JOURNALS

## JOURNAL OF SCIENTIFIC INSTRUMENTS

No. 9, 1960

J. Wilbur-Ham and others. Error of rectifier-type milliameters in low-resistance circuits.

No. 10, 1960

P. Hariharan. Cyclic shearing interferometer for testing optical systems.

L. Clarke. Transformer bridges for use with resistance strain gauges and similar transducers.

J. Adlam. Production of millimicrosecond current pulses using a pressurized spark gap.

No. 11, 1960

A. Lodge. Low-compliance diaphragm-capacitance gauge for measuring liquid pressures of the order of 25 mm water; zero stability of 50 $\mu$ water.

P. Hariharan and others. Measurement of the optical thickness of absorbing specimens with a three-beam interferometer.

No. 12, 1960

J. Adington and L. Molyneux. Portable water velocity meter.

L. Ford. Stability of some reactance standards (capacitance, inductance, mutual inductance) used in the National Physical Laboratory for calibrating inductance and capacitance.

C. Thorne. Temperature-control system for use with a spectrophotometer.

B. Ashwin in others. Viscometers having damped torsion oscillations.

A. Hayward. Improved design of portable vacuum manometer for measuring absolute pressures in the range of 10 to 30 mmHg.

W. Hood and others. Liquid-level alarm using internally reflected light.

C. Harris. Method for increasing the range of a flowmeter by using capillary resistances.

No. 1, 1961

C. Barber. A platinum resistance thermometer for use at high temperatures up to 1063°C.

E. Gillham. New design of spectropolarimeter, which combines the function of a monochromator and polarimeter by using quartz prisms.

## MESURES & CONTROLE INDUSTRIEL

No. 283, December, 1960

New determination of the meter in terms of the orange krypton-86 spectral line (Resolution of the 11th General Conference on Weights and Measures, held in Paris on October 14, 1960).

L. de Broglie. The expected early publication of the decree on the adoption in France of the new system of measuring units (meter, kilogram, second, ampere, candle and °K).

A, Ferry. The problem of an inch or metric system of units.

German instrument making at the International Instrument -making Exhibition "Interkama" held in Dusseldorf in 1960.

Galvanometers with signal contact, "galvanometric relays" and their application.

Application of precision potentiometers. Direct and indirect measurements by means of potentiometers, design of potentiometers, recording and tracking potentiometer devices.

L. Vallet. Possibilities of industrial application of junction-type transistors.

No. 284, January, 1961

M. Manlou-Dumesnils. Four definitions of the meter. Historical review of the origin of the meter and its determinations.

Resolution of the 11th General Conference of Weights and Measures (Paris, October, 1960).

J. Gontie. Optical methods of observations and measuresments in gases (interferometer, shadow and striascopic).

Devices for automatic regulation and control, exhibited at the "Interkama" exhibition in Dusseldorf in 1960.

## FEINGERÄTE TECHNIK

No. 1, 1961

K. Trautman. Basic problems in unifying national enterprises "Control technique, instrument-making and optics" in 1961.

W. Gross. Transformer for measuring the torque and other mechanical properties of small instruments.

S. Lieberwirt. Report on the Hungarian optical conference, held in 1960.

H. Kortum. International conference on instruments and measurements (Stockholm, September 13-16, 1960).

Brief report on the conference on physical measurements in chemical analysis, measurements of electrical and magnetic quantities, and measurements in the sphere of nuclear physics and control techniques.

## FEINWERK TECHNIK

No. 1, 1961

G. Ulbricht. The role of balances as measuring instruments. A historical review of the development of various types of scales, their modern construction and characteristics.

K. Gedeke. Capillary depression in mercury barometers and manometers.

## NBS TECHNICAL NEWS BULLETIN

No. 12, 1960

A new international standard of length, that of the krypton-86 luminous radiation wavelength.

Effect of moisture on analytical balances. Results of investigations conducted by the NBS.

# INFORMATION

## HIGH-PRECISION MEASURING INSTRUMENTS

P. P. Arapov

Translated from Izmeritel'naya Tekhnika, No. 4,
pp. 58-60

Hall No. 21 on "Metrology, Standards, and Precision Measurements" of the "Engineering" pavilion has been supplemented since January, 1961, by many exhibits of new reference and precision instruments constructed at the scientific-research institutes of the Committee of Standards, Measures, and Measuring Instruments and by our industrial establishments.

These instruments feature our achievements in providing uniform, accurate, and correct measurements in our country and the part they play in science and technology.

Several new exhibits show the possible versions in attaining mechanization and automation of labor-consuming inspection and adjustment operations, and the increased efficiency attained by their use in production and inspection processes.

One of the stands is dedicated to the task set by the plenary session of the CPSU (Communist Party of the Soviet Union) central committee (1959) on the procedure for developing, manufacturing and testing experimental models of machines and instruments, and for starting their mass production. State testing of measuring instruments for the purpose of determining whether the newly developed instruments meet the requirements of our national economy and the up-to-date technical level of our own and foreign measurements technology are also shown on this stand. Tests at various stages of the instrument manufacture are graphically demonstrated right from the development specification to mass-production testing. Obsolete instrument types whose production has been stopped as a result of state testing are demonstrated.

In the section on "linear measurements" considerable attention is paid to the modern interferometer method of measuring. The posters on the stand deal with the reproduction of light wavelengths which are the basis of modern methods for measuring lengths and angles, and information on the new standard length, that of the wavelength of the krypton-86 orange line, is given. Various examples demonstrated the wide use of interferometer methods in measurement techniques.

The exhibition contains a number of actual interferometer instruments for various types of measurements, including the PKM set developed by the NGIMIP (Novosibirsk State Institute of Measures and Measuring Instruments) for checking precision mechanical lever instruments, such as mikrokators, optical measuring machines, extensometers and other instruments with a measuring limit of 2 mm. Microindicating gauges with a scale of 1 and 2 mm are checked on the PKM set by means of a measuring microscope with an optical micrometer and a linear scale. More accurate instruments with smaller measuring limits are checked by an interferometer method. The errors of the PKM set do not exceed in checking optical measuring machines ±0.00004 mm, in checking mikrokators, ±0.00008 mm, and in checking microindicating gauges ±0.001 mm.

In the section on "Measurements of mass" a new stand deals with the mechanization of measurements by means of large scales which previously required a considerable expenditure of labor. Data are exhibited which show new means of mechanizing measurements and the greater efficiency gained by their application.

Two working models of these devices are shown.

1. The weighing equipment for checking motor-truck and other large-capacity scales, developed and produced by the VNIIK (All-Union Scientific Research Institute of the Committee of Standards, Measures and Measuring Instruments). The equipment is intended for checking 10-ton scales. The checking equipment and hoisting device are mounted on the body of a ZIL-151 motor truck and its trailer (the description of the equipment was given in the journal "Measurement Techniques" No. 10, 1959). This equipment considerably raises productivity, improves the inspec-

tor's conditions of work, and reduces to one-third the time required for checking. Moreover, the use of this equipment for testing motor-truck scales alone will produce a saving to our national economy of 1 million rubles (new rubles).

2. The equipment for checking mobile unequal-arm scales, developed by the same institute. The equipment has an electrically operated tackle with a capacity of 500 kg for lifting and displacing grade III reference weights. The tackle runs along a single rail. The use of the above device and reference 500 kg weights instead of the previously used 20 kg weights has made it possible to mechanize the equipment and reduce the testing time to two-thirds.

A new stand showing a reference method for determining the moisture content of grain, developed by the VNIIK and the VNIIZ (All-Union Scientific-Research Institute of Grain and Grain Products) and based on extracting moisture by heat drying in vacuum and measuring the loss of mass in a sample of grain. The stand includes the actual reference vacuum-heat equipment for measuring the moisture content of grain, developed by the VNIIK for checking moisture meters and making accurate measurements of moisture content.

This équipment includes a vacuum-drying controlled thermostat, a forevacuum pump, special grain hoppers with a milling device, and analytical balances. The error of measurement of this equipment does not exceed ±0.1%.

By means of this equipment it will be possible to calibrate electrical moisture meters with an error not exceeding 0.5-1% as against 1.5-2% attained at present by calibrating them in standard drying cabinets. The considerable improvement in the accuracy of measurements will make it possible to use moisture meters in mass measurements of the moisture content of grain during its delivery, thus improving the qualitative control of grain in the country.

A reference grade 1 micromanometer type MNP-1, developed by the VNIIM for checking grade 2 micromanometers and laboratory instruments in the range of 400 to 4000 kg-wt/m$^2$ is shown in the section "Measurements of Pressure, Velocity and Acceleration." The micromanometer uses a cylinder with an unsealed piston. The measured pressure is fed under the cylinder of the micromanometer and at the same time to the instrument under test. The pressure is balanced by means of weights placed on the pan of the piston. The total force exerted by the weights and the piston device divided by the effective area of the piston determines the measured pressure.

The VNIIK is showing its reference piezoelectric accelerometer for calibrating and checking commercial accelerometers. The instrument consists of a piezoelectric acceleration converter (transducer) with a barium-titanate sensing element, a cathode follower, an alternating calibrating and an electronic oscilloscope used as a comparator of the output voltage. The instrument has two measuring ranges of 0.5-25 g and 2-100 g. The sensitivity of the first range is 20.4 mv/g and of the second 5.7 mv/g. The relative error in measuring the output voltage does not exceed 2% over the whole measuring range.

A reference instrument for determining the hardness of metals by means of a diamond pyramid, developed by the VNIIM, is shown in the "Measurements of force and hardness" section. The instrument is intended for calibrating reference hardness gauges by means of which the commercial type TP hardness gauges are calibrated. The effort is conveyed to the tip by means of direct loading, the pressing in of the tip, the duration of the test and the unloading are automatically controlled. The optical reading device provides a very accurate measurement of the indentation diagonal. The quadratic mean error of measurement does not exceed ± 0.3%.

The "Temperature measurements" section has been supplemented by two VNIIFTRI (All-Union Scientific Research Institute for Physico-Technical and Radiotechnical Measurements) exhibits.

1. The reference platinum thermometer for checking reference, calorimetric and laboratory thermometers, and also for accurate measurements of temperature in the range of -183 to +630°C. The instrument consists of a highly sensitive four-conductor resistance thermometer made of commercial platinum with a temperature resistance coefficient $R_{100}$ ($R_0 \geq 1.3923$). The thermometer's sensing element consists of a platinum 0.1 mm wire wound bifilarily over a helical quartz former. The wires are welded to four leadout conductors which are connected to the output terminals.

2. Reference platinum thermometers for low temperatures, which serve to check reference copper-constantan thermocouples and for measuring low temperatures in the range of 10 to 300°K.

The thermometer's sensing element consists of a 0.05 mm platinum wire. Its maximum error in measuring temperatures does not exceed 0.01°C, and in measuring temperature differences 0.002°C over the whole measuring range.

The VNIIK has developed and is exhibiting an equipment for measuring low temperatures in the range of -40 to -255°C at 20 points by means of an electrical resistance thermometer method. The temperature transducer consists of the above-mentioned thermometer. The transducer resistance is measured by means of a special ac bridge. Its output voltage, which varies with the resistance of the transducer, is measured by a moving coil galvanometer connected to a phase-sensitive circuit which consists of two crystal diodes. The measurement error of this set does not exceed ± 0.5°C.

The VNIIM is exhibiting a mobile equipment (UVP-R) for checking secondary thermal control instruments, such as electronic potentiometers and millivoltmeters used with thermocouples, and electronic balancing bridges and ratiometers used with resistance thermometers. The equipment is mounted in two cases of a total weight of 20 kg.

The total emf measuring range amounts to 125 mv with a minimum calibration of 1 μv, and that of resistance to 1000 ohm with a minimum calibration of 0.01 ohm. The error of the resistance box does not exceed ±0.02%, and that of the potentiometer $\pm(5 \cdot 10^{-4}\, U_x + 1.3\,\Delta U)$ mv, where $U_x$ is the measured emf in mv, and $\Delta U$ is the smallest calibration of the pointer scale in mv.

A measuring and checking equipment type IPU-01 for testing under operating conditions electronic automatic instruments used in thermal power control (potentiometers, millivoltmeters, bridges) is exhibited by the Leningrad Sovnarkhoz (Council of National Economy). The equipment can also be used as a source of controlled direct current and as a box with a continuously variable resistance for checking other electrical instruments. The equipment weighs 12 kg and is mounted in a box.

The "Electrical and magnetic measurements" section has received over 20 exhibits, presented by the Committee's institutes and instrument-making plants. The new exhibits include a three-phase reference electricity meter type OS-3 developed by the VNIIK for checking single and three-phase electricity power meters and wattless power meters, grades 2 and 2.5. The measurement errors of the meter do not exceed ±0.3% for $\cos\varphi = 1$ and ±0.4% for $\cos\varphi = 0.5$. Its temperature error is compensated by means of thermistors with a negative temperature coefficient. This electricity meter also includes a frequency compensation circuit.

The Moscow electricity meter plant is exhibiting an automatic equipment type APK-58, developed by the VNIIK for checking electricity meters. The tested meters are placed on a hexahedral drum which rotates through 1/6 of a turn each 48 sec, during which the meter is tested under set conditions. Each meter is tested under five conditions: at 150, 50 and 10% of its normal current for $\cos\varphi = 1$, and at 100 and 20% of its normal current for $\cos\varphi = 0.5$. The readings of the tested meters are compared with two reference meters. The testing cycle of one meter amounts to 3.67 minutes, the testing error does not exceed ±0.25%. The maximum testing capacity of the equipment amounts to 450 electricity meters per hour with one person operating the equipment.

A portable equipment type UPSR for checking single and three-phase electricity power and wattless power meters as well as phase meters, ammeters, voltmeters and wattmeters grade 0.1 and less accurate types, is exhibited by the VNIIM. The equipment consists of two independent single and three-phase circuits, one for measuring currents of a nominal value of 0.5 to 50 amp, and the other for line voltage of a nominal value of 150 to 450 v. The complete set comprises three units mounted in a case weighing 20 kg, and consists of instrument transformers, ammeters, voltmeters and three reference wattmeters.

The VNIIK has developed reference voltage transformers type TNP for higher frequencies, intended for extending the voltmeter range up to 2 kv in the band of 100 to 10,000 cps. The nominal value of primary voltages are 400, 500, 800, 1000, 1200, 1500 and 2000 v; the nominal secondary voltage is 100 v, and the grade of accuracy 0.2.

The Sverdlovsk branch of the VNIIM is exhibiting a stabilized source of a sinusoidal current "Stabistor 300/30," intended for supplying measuring instruments and equipment with an alternating current of a commercial frequency. The instrument provides currents up to 30 amp with a harmonic content not exceeding 1.5% at a voltage of 300 v with a nonlinear distortion coefficient not exceeding 0.8%. The variations of voltage or current at the output of the "Stabistor 300/30" do not exceed ±0.2% for mains voltage variations of ±5%.

The "ZIP" plant of the Krasnodar Sovnarkhoz is exhibiting potentiometer R 330 for measuring emfs and voltages in two ranges of 201.11 mv and 20.111 mv, potentiometer bridge R304 for measuring emfs, voltages and resistances; a dc single and double bridge R329 for measuring resistances; and potentiometer R307, and other instruments.

The "Tochélektropribor" plant of the Kiev Sovnarkhoz is exhibiting reference capacitors R533, R534, and R535 for calibrating and checking commercial measuring capacitors at voltages up to 200 v; a capacitance box R513; an inductance box R538, etc.

In the "Measurements of time and frequency" section the KhGIMIP (Kharkov State Institute of Measures and Measuring Instruments) is exhibiting high-Q vacuum quartz crystal resonators. The Q-factor of the elements amounts to 2 to 5 millions.

In the section "Radiotechnical measurements" the VNIIFTRI is exhibiting models of the following instruments: 1) a set of matching transformers for matching waveguides and coaxial lines in precision measurements; 2) a set of reference waveguide terminators ON, for checking waveguide lines in the range of 1.75 to 4.20 cm wavelengths. The reference terminations are certifiied in the frequency range of the waveguide with which thay are used for an error not exceeding ±1.5%; 3) reference thermistor heads OTGV, intended for use with reference thermistor bridges at superhigh frequencies. The set consists of four heads for the range of 1.8 to 5.4 cm wavelengths. The heads are certified by their efficiency with an error not exceeding ±5%. 4) An equipment for calibrating measuring microphones used in calibrating reference and commercial measuring microphones in the range of 20 cps to 20 kc, with an error not exceeding ±.1%.

Reference high-frequency standards of conductance and susceptance developed by the NGIMIP are also exhibited in the same section. These standards are intended for checking parameters of circuits at frequencies up to 200 Mc. The conductance standards consist of disc resistors made of thin-layer resistance elements obtained by condensation of precious metal vapors in vacuum. The resistors cover a range from 5 to 2000 ohm, the standards are certified with an error not exceeding ±1%. The susceptance standards consist of disc screw capacitors of 40 to 400 μμf, whose capacitance error at the highest frequency does not exceed ±0.5%.

The above-mentioned exhibits illustrate the achievements of the Committee's institutes and the instrument-making plants in their work for the improvement of our metrology and instrument-making industry.

## SOVIET-MADE EQUIPMENT WITH RADIOACTIVE ISOTOPES

V. S. Merkulov

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In 1960, a topical exhibition on the "Use of radioactive isotopes for production control and automation," was organized in the "Atomic Energy" pavillion by the Atomic Energy Utilization State Committee attached to the Council of Ministers of the USSR in conjunction with the "Peaceful Utilization of Atomic Energy" Committee of the Council for the Exhibition of the Achievements of the National Economy of the USSR.

Over 150 exhibits of installations, instruments and devices, including dosimetric apparatus and protection equipment, were shown. The widest representation was given to various types of radioactive relay devices, level indicators, thickness meters, density meters, fault locators, and other instruments used in the most diverse branches of industry.

Considerable interest was aroused by typical β and γ-radiators type BI-1, BI-2, GI-1 and GIP-1, radioactive transducers RD and universal electronic relay units URAP of various types, used as component parts in various automatic monitoring and control devices which employ radioactive isotopes. The BI-1 and BI-2 radiators use $Sr^{90}$ with an activity of 0.5 and 0.2 mC, respectively, and radiators GI-1 and GIP-1 (float) use $Co^{60}$ with an activity of 100 and 0.5 mg-eq of radium, respectively. The radiators are hermetically sealed. Transducers RD are intended for registering the radioactive isotope radiations and converting them into electrical pulses. Transducers of β-radiations type RD-6 and RD-9M are supplied with gas-discharge counters STS-5, and transducers RD-10 with counters STS-12. The transducers of γ-radiations type RD-11M are supplied with counters STS-1, and transducers RD-14 with five, and RD-15 with ten counters type STS-5. The above transducers are used with receiving units URAP-2AM and URAP-3DM, which amplify the electric pulses received from the transducers and transmit them to the actuating mechanism.

As an example of the utilization of standard elements and units one can cite the standardized apparatus for production control by means of registering modulated batches of $\beta$-radiations, which can be used for measuring the speed of rotation, lengths of sheet and strip materials, liquid flows, etc.

Original exhibits consisted of experimental models of instruments for automatic analysis of the composition of substances types RAZh-1A and ATZh-1 and a factory instrument RPSN-1. The stationary automatic analyzer RAZh-1A with recording and indicating instruments is intended for continuous determination or corrosive binary liquid concentrations. The particular type of instument shown at the exhibition is designed for determining concentration of aqueous solutions of methanol (scale 65-85% of methanol) in the production of formalin with an error not exceeding ±5% of the full scale reading. The principle of operation of the analyzer is based in the relation between the degree of absorption of $Sr^{90}$ $\beta$-radiation and the composition of the analyzed solution. The instrument is provided with periodic automatic checking and correction of the zero reading and scale range. The instrument transducer is made explosion-proof. Automatic analyzer ATZh-1 is intended for continuous determination of the concentration of one of the components in a three-component liquid with an error of ±10%. It uses both the absorption and reflection method of $SR^{90}$ $\gamma$-radiatioh. The radiations are registered in ionization chambers. Instrument RPSN-1 serves to determine the content of sulfur (in the range of 0.5-2.0%) in oil products, with an error of ±0.05%. It uses as a source of radiation $Fe^{55}$ and as a receiver a gas-discharge counter.

A radioactive transducer of solution concentrations was also exhibited. Its sensing element consisted of a combination of an areometer and a thermometer which sends electrical signals to an automatic control of signalling system when the concentration deviated from its normal value. The source $Co^{60}$ (0.1 mg-eq of radium) is placed in a capillary tube on the surface of the thermometer mercury column, the radiations are registered by means of two gas-discharge counters type SI-1BG. The transducer type shown at the exhibition is designed for measuring 55% concentration of nitric acid. A pulse is sent to a signalling or recording device when the nitric acid concentration varies by ±0.2%. Sets RKK-B-1 and LBKK (laboratory type) with radiation receiving gas-discharge counters are designed for measuring potassium concentrations in potassium salt solutions by recording $\beta$-radiations from a natural radioactive $K^{40}$ isotope. The above-mentioned concentration meters measure the content of potassium in solution (for concentrations up to 20%) with an error of ±1.5%.

Of the geological prospecting instruments shown at the exhibition, mention should be made of the following:

A field equipment VIMS-58 for a complex analysis of the composition of ores and metals by x-ray radiation methods in working conditions. The method is based on stimulating characteristic x-ray radiations from the element under test, and then analyzing these radiations. The primary radiation source consists of $Tu^{170}$ with an activity of 1-5 C, and the receiver of a single-channel scintillation spectrometer which comprises a photomultiplier FÉU-1S and an NaI(Tl) crystal. The accuracy of the analysis amounts to 5-10%.

A universal laboratory equipment FNUV-4-59, for a quantitative determination of beryllium in samples of ore concentrates and products of their metallurgical processing. The equipment consists of a neutron radiation meter type S4-3 and a measuring chamber, whose principle of operation is based on nuclear reaction (n, $\gamma$). The source of $\gamma$-radiations consists of $Sb^{124}$ isotope with an activity of 50 mC, and the slow neutrons detector of 4 gas-discharge counters type SNMO-5.

A field instrument PRLA-1 with a $Tu^{170}$ source for detecting diamonds in ores and diamond concentrates. Its operation is based on the luminescence produced by exciting the mineral with $\gamma$-rays.

The "Neitron" equipment which consist of a highly efficient scintillation slow-neutron detector, a Po-Be source with an activity of 0.01 Curie Po, a moderating unit, and a transistorized amplifying and recording circuit. The equipment is designed for detecting in rock samples the presence of boron, lithium, cadmium and other elements with abnormally high slow-neutron absorption cross sections. This equipment can also be used for determining the content of water in rock samples when any of the above elements are absent.

A scintillation emanometer with photomultipliers FÉU-16 or FÉU-35 for field emanation prospecting, measurement of the amount of radon and thoron in radiochemical analysis, and for determining emanation concentration in air for dosimetric purposes. This group of instruments is closely related to installations for investigating oil and other wells by $\gamma$-ray, neutron-gamma-ray and gamma-gamma-ray logging method. Portable equipment for radioactive logging $\gamma$-59, RKM-5 and RK (double channel) were also shown, as well as warning control apparatus type ARPK-1 for tracking a well shaft being sunk in an inclined thin layer of coal. In the ARPK-1 equipment the radiation source $Co^{60}$ (20mC) is placed in the cutter, whereas the well probing detector is placed behind it for registering the scattered $Co^{60}$ $\gamma$-radiations.

The exhibition also included a large assortment of radioactive devices for measuring and maintaining the level of liquid and loose media in enclosed containers, and of devices for signalling the boundary between two media with different densities. For instance, factory indicators and regulators of the level of liquid and loose media RPRU (5 types), BIU (2 types) and GIU (6 types), consisting of electronic relay units URAP, radioactive transducer RD and standard radiators BI-2, GI-1 and GIP-1. For automatic monitoring or maintenance of a set level in the boundary between two media with different densities, several level indicators were used, those with cobalt radiation sources type ARPU, with cesium sources type RIU-1 and RIU-2, as well as a monitoring system UR-6A ($Co^{60}$ source), and a regulator type RUV-1 of the water level in steam boilers (source $Cs^{137}$). The exhibits also included a multichannel level indicator MU-32 for measuring the height of the charge in blast furnaces, level regulator RRU-2 for monitoring and controlling the level of cloth in steaming chambers, a standardized level regulator URU-6 for maintaining the level of liquid steel in crystallizers of continuous casting machines, a single-position level indicator URP-1013, and a three-position level indicator SPURT-1 for signalling the position of the level and determining the degree of filling in enclosed vessels, bunkers, metallurgical furnaces and other containers. The exhibits also included a level indicator with telephone transmission type IU-3 of liquefied gas in cylinders, a regular and level indicator with a pneumatic output type RUP-1, and other level indicators. All the above-mentioned levelmeters used gas-discharge chambers as receivers.

Considerable interest was displayed in radioactive relay devices. For instance, the gamma-relay GR-1 (with 5 counters STS-5), relay GR-2 (with 6 counters STS-6), and GR-3, (with 3 counters STS-6), equipped with collimators as well as gamma-relays GRV with GÉRV receivers (with STS-8 counters) for monitoring material in a controlled space. Their radiators consist of $Co^{60}$ and $Cs^{137}$. These relays are used in automatic production monitoring, for instance, in coal mines the explosion-proof relay GRV is used. The exhibits also included single-channel gamma-relays type GROM-1, with $Co^{60}$ sources for signalling the presence of material in tanks, pipelines, conveyor belts, etc., as well as gamma-relays GR-1052 for determining the of filling of bunkers, metallurgical furnaces and other containers filled with liquids, lumped and loose materials. This group of devices includes the above-mentioned universal relay instruments URAP-2AM (with RD-6 or RD-14 transducer) and the modernized instruments type URAP-3DM with standard transducers. There was also shown a relay type RPP-1 with STS-8 counter for recording rock densities. Developed for discrete unloading of upsetting machines in washing plants. This group includes a working radioactive regulator RK-4 intended for continuous automatic control in filling opaque containers. The automatic device counts up the finished products and controls an automatic sorting system according to a set standard. The productivity of the device amounts to 150 containers per minute.

Gauges for measuring the thickness of sheet materials, coverings, pipe walls, and the density (weight per unit surface) of materials, used in automatic systems for the production of various commodities (see table) were widely represented at the exhibition.

Radiographic equipment was widely exhibited. In addition to the well-known powerful industrial (and therapeutic) gamma installations GUP-Co-0.5, GUP-Co-5, GUP-Co-50 and GUT-Co-400-1. several portable sets for radiographic monitoring were also shown, including a portable set RK-1 using a $Tu^{170}$ source with an activity of 0.5 g-eq of radium (with an automatic or manual control of the preparation), and a portable set PUR-1 using a $Tu^{170}$ source with an activity of 3 g-eq of radium, or $Eu^{170}$ with an activity up to 5 g-eq of radium (with a remote control preparation), which provide radiograms under factory and field conditions. These sets provide transmission of radiations through steel plates 1-15 mm thick and aluminum alloy 5-50 mm thick. A mobile automatic set GUP-A-2M using a $Co^{60}$ source with an activity of 1 g-eq of radium for gamma-radiography of welded joints in steel constructions 110-120 mm thick. A flaw-detector RDB-2 for reinforced concrete using a $Co^{60}$ source with an activity of 30-70 mg-eq of radium intended for detecting faults in assembled reinforced concrete units. A portable set GUP-5-2 with remote control and a combination protection for gamma-radiography under factory and field conditions. The equipment uses preparations of $Ir^{192}$ with an activity of 5 g-eq of radium or $Cs^{137}$ with an activity of 2 g-eq of radium, and is intended for transmitting radiations through steel sheets 12-60 mm thick, and through other materials of an equivalent thickness.

A number of instruments for investigating other parameters are also of considerable interest. For instance, there was exhibited a neutron moisture-content meter IVN-1 for checking the moisture of loose materials (moulding earth, building materials, iron ore concentrate, etc.) which contain hydrocarbons or such neutron-absorbing materials as cadmium and indium. Its neutron radiation source consists of a Po-Be radiator with an activity not less than $10^6$ neutrons per second. Its receiver consists of a scintillation counter. Its range covers 0-12% of moisture content (by weight) and its measurement error is $\pm 0.6\%$.

Radioactive (R) Thickness Gauges, Differential Wall-Thickness Gauges, Density Meters, Pulp Meters, and Coating Thickness Gauges

| Name | Type | Application | Range | Error | Source | Receiver |
|---|---|---|---|---|---|---|
| Thickness gauges | TU-495<br>ITSh-49 | Measuring the thickness of rolled steel | 0.05-1.0 mm<br>0.03-0.8 " | ±1.5% | $Ce^{144}$<br>$Sr^{90}$ | Compensation-type ionization chamber |
| Beta-type coating thickness gauge | BTP-1<br>BTP-2 | Selective checking of coating thicknesses | to 30 mg/cm$^2$<br>" 65 " | ±2.0% | $Tl^{204}$ | ditto |
| Equipment for measuring the thickness of a metal strip by means of a scintillation counter | | Measuring the thickness of a cold-rolled steel strip | 0.05-1.0 mm<br>0.03-0.6 "<br>0.002-0.15 " | ±0.5 μ<br>±2 "<br>±2 " | $Ce^{144}$<br>$Sr^{90}$<br>$Tl^{204}$ | Scintillation counter |
| Universal thickness gauge | URIT-1 | Measuring the deviation of sheets from their nominal thickness | 50-5000 g/m$^2$ | ±3% | BI-1 | Ionization chamber |
| Contactless weight gauge | BIV | Determining the weight of fabrics (or substances covering fabrics) | 200-800 g/m$^2$ | ±5% | $Tl^{204}$ | ditto |
| Radioactive thickness gauge | TR-3 | Measuring wall thickness of hollow components | 0.5-5 mm | | $Tu^{170}$ | Gas-discharge counter |
| Radioactive thickness gauge | RT-2 | Checking the thickness of copper conductors on pertinax plates of printed circuits (by means of reflections) | 10-100 μ | ±10% | $Sr^{90}$ | ditto |
| Gamma-ray thickness gauge | GT-17-12 | Measuring the thickness of sheet steel and steel pipes when one side is accessible | to 12 mm | ±4% | $Co^{60}$ | Scintillation counter |
| Pulp density meter | IPP | Measuring and controlling pulp density | 1.0-1.5 g/cm$^3$<br>1.6-2.1 " | ±1.5% | $Cs^{137}$ | Ionization chamber |
| Radioactive density meters for liquids | PZhR-2<br>PZhR-5 | Measuring, recording and controlling the density of various liquids | 1-1.5 g/cm$^3$ | ±5% | $Co^{60}$<br>$Cs^{137}$ | Gas-discharge counter, ionization chamber |
| Coating thickness gauge | ITP-476 | Measuring tin and other coatings on a steel strip | 0-5μ | ±0.15μ | $Tl^{204}$ | Ionization Chamber |
| Gamma-ray earth gauge | GK-1584 | Measuring and recording the volumetric content of earth in an excavation pump pulp | 0-40% | ±1% with earth | $Co^{60}$ | ditto |
| Gamma-ray density for oil products | GPN | Checking the variation of oil product densities during their pumping along a pipeline | 0.7-0.9 g/cm$^3$ | ±1% | $Co^{60}$ | Scintillation counter |
| Measuring tin and other coatings on a steel strip | IPP-2 | Measuring the pulp density | 1-1.3 g/cm$^3$ | ±5% | $Co^{60}$ | Gas-discharge counter |
| Volumetric weight gauge | IOV-2 | Determining the volumetric weight of building units and concrete samples (by means of reflections | 500 × 300 × 100 mm | ±1% | $Co^{60}$ | ditto |

TABLE (continued)

| Name | Type | Application | Range | Error | Source | Receiver |
|---|---|---|---|---|---|---|
| Radioactive density meter | RP-2-60 | Measuring the density of freshly-laid concrete blocks | 2-2.6 ton/$m^3$ (normal concrete) | 1.5-2% | $Co^{60}$ | ditto |
| Instrument for checking irregularities in canvas | RPN | Checking the weight of canvas on a stripping machine | 150-700 g/$m^2$ | | $Tl^{204}$ | Ionization chamber |
| Radiation reflection thickness gauge for settled coal dust | ROTOP-3 | Measuring the quantity of coal dust which settles on the surface of pit workings | 0-70 g/$m^2$ | ±10% | $Tl^{204}$ | |
| Differential wall-thickness gauge | R-6M | Checking the thickness and the difference in the two thicknesses of a bimetallic thin-walled pipe | to 800μ (for diameters of 20 mm) | ±2% | $Tu^{170}$ | Ionization chamber |

In addition to the well-known manometer MIR-3A for measuring the pressure of various noncorrosive vapors and gases in the range of 0.01-10 mmHg, there was also exhibited an ionization methanometer TM-4 with tritium targets of an activity 7-10 C for determining the atmospheric concentration of methane in the range of 0-5% in coal mines, metallurgical and chemical plants. The maximum error of the instrument is ±0.2%.

The exhibits included a radiation marker of cable copper conductor joints (using a cobalt source and a gas-discharge counter) for an automatic location of joints in a continuous cable-vulcanization equipment; an automatic device AKO-1 with a $Co^{60}$ source (0.02 mC) for tapping and registering hydrocarbon condensates of centrifuge sumps in gas fields; an automatic control system SARZ-4 for an excavating pump with a set of transducers for various purposes such as controlling the intake of earth by changing the speed of the excavating pump propulsion along the cutting, taking as a criterion for this purpose the saturation of the pulp with earth; a tracking system RR-9/RT-106 attached to an equipment for machining pipes which consists of a contactless transducer of an automatic control system for the RT-106 equipment; it uses a $Tu^{170}$ radiator (0.1 g-eq of radium) and a scintillation counter receiver.

Deserved attention was aroused by automatic regulators of heat, voltage level and current density, which used point $\beta$-radiators and gas-discharge counters. One such regulator was developed, for instance, for controlling the density of galvanic vats.

Many of the above instruments will be sold in 1961, together with their radiation sources by the All-Union agency "Isotope" of the "Soyuzreaktiv" trust, at the customers' requests in the Moscow shop "Isotopes."

This exhibition of Soviet-made instruments using nuclear radiations has shown the great achievements of our instrument-making industry in the sphere of the application of atomic energy for peaceful purposes, and aroused great interest of those who visited the exhibition.

# PERMANENT SEMINAR ON PROBLEMS OF DESIGNING AND USING MEASURING-COMPUTER EQUIPMENT

V. S. Popov

Translated from Izmeritel'naya Tekhnika, No. 4, p. 64, April, 1961

In December, 1960, the LONITOPRIBOR (Leningrad branch of Scientific, Engineering and Technical Society of Instrument Makers) called the first conference of the permanent seminar on problems of designing and using measuring-computer equipment. At the conference 16 papers were read and discussed.

The seminar was attended by more than 200 representatives of higher educational establishments, institutes of the USSR Academy of Sciences, scientific-research institutes, independent and special design officers, plants and other organizations designing or using measuring-computer equipment.

I. G. Gol'dreer's paper on "Selectively stabilizing measuring computers" deals with a new principle of designing analogue computers. They consist of automatically controlled static voltage dividers which vary the voltage ratio in such a manner that one of the values fed to the input remains constant at the output. By means of these devices it is possible to perform any algebraic operation with an error not exceeding ±1%.

V. S. Popov read a paper on automatic and measuring instruments with heater resistors for measuring various electrical and nonelectrical quantities. By means of such instruments over 20 different quantities can be measured.

In their paper, V. B. Smolov and E. P. Ugryumov deal with designing transistorized miniature low-voltage multiplying and dividing devices of a time-pulse type, operating over a wide temperature range with an error not exceeding ±1%. Considerable attention is paid in this paper to circuit compensation methods of temperature errors in the main units of the device.

A. F. Fokin deals in his paper with a device for computing potential fields by simulating them on an electrical conducting paper.

N. S. Blat deals in his paper with computers for converting scales and introducing in processing measurements of physical phenomena recorded on a rectangular coordinate chart.

P. I. Kotlyarov examines in his paper problems of introducing manually into information which is at the same time expressed in a binary code.

V. P. Mikhailychev's paper deals with an induction type "shaft-digital" converter.

In his paper, L. P. Gorokhov examines the design and principle of operation of an "angle-code" commutator convertor.

V. P. Shagurin reported on a transistorized "voltage-digital" convertor.

G. I. Gil'man and K. M. Chugunov deals in their paper with an electronic convertor of thermocouple and resistance thermometer signals to a standard direct voltage signal. The convertor provides a linear relationship between the output voltage and the measured temperature, and can be used in automatic digital recording systems.

In their paper entitled "Photoelectric instruments based on the utilization of selective compensation circuits," I. G. Gol'dreer, M. L. Petrova, and O. P. Khvostov deal with instruments developed by the Independent Design Bureau of the USSR Ministry of Geology and Preservation of Natural Resources for measuring simultaneously several luminous flux ratios. The readings of these instruments are not affected by external factors.

S. M. Mandel'shtam deals in his paper with certain problems in the theory of telemetering code rings and examined the design of rotation angle to code converters. He notes certain applications of measuring computers for decreasing errors in dimensional coding systems.

In this paper, S. V. Shalaev examines the possibility of interpreting gravity and magnetic prospecting observations by means of electronic computers. This interpretation is based on approximating the curves representing the observation result means of rational fractions. An equipment has been developed for semiautomatic and automatic interpretation of magnetic prospecting curves.

I. G. Gol'dreer and S. M. Mandel'shtam in their paper on "Basic trends in the development of computers" propose a classification of these devices. Considerable attention is paid by the authors to the conversion of various quantities into a form suitable for analogue and digital computers.

In his paper, Yu. I. Nikol'skii deals with simulating computers for transforming potential fields. The device is intended for a complex separation of gravitational fields, the conversion of magnetic and gravitational fields into the upper half-space and the calculation of higher derivatives.

E. P. Balashov, I. A. Nazarov, V. B. Smolov, A. L. Perel'man, and V. M. Sternin reported on digital-analogue electronic computers for an acoustical logging station.

In the concluding session of the conference a decision was adopted which outlines the ways of improving and coordinating the scientific-research work in the sphere of measuring computer techniques. The resolution notes that the basic trend in the further work of the seminar should consist of elucidating new developments in the sphere of computers used for measuring purposes, new work in the sphere of measuring components for computers, the application of measuring-computers for total production-automation and for scientific research.

# Soviet Journals Available in Cover-to-Cover Translation

| ABBREVIATION | RUSSIAN TITLE | TITLE OF TRANSLATION | PUBLISHER | TRANSLATION BEGAN Vol. | Issue | Year |
|---|---|---|---|---|---|---|
| AÉ | Atomnaya énergiya | Soviet Journal of Atomic Energy | Consultants Bureau | 1 | 1 | 1956 |
| Akust. zh. | Akusticheskii zhurnal | Soviet Physics – Acoustics | American Institute of Physics | 1 | 1 | 1955 |
| | Antibiotiki | Antibiotics | Consultants Bureau | 4 | 1 | 1959 |
| Astr(on). zh(urn). | Astronomicheskii zhurnal | Soviet Astronomy–AJ | American Institute of Physics | 34 | 1 | 1957 |
| Avto(mat). svarka | Avtomaticheskaya svarka | Automatic Welding | British Welding Research Association (London) | | 1 | 1959 |
| | Avtomatika i Telemekhanika | Automation and Remote Control | Instrument Society of America | 27 | 1 | 1956 |
| | Biofizika | Biophysics | National Institutes of Health* | | 1 | 1957 |
| | Biokhimiya | Biochemistry | Consultants Bureau | 21 | 1 | 1956 |
| Byull. éksp(erim). biol. i med. | Byulleten' éksperimental'noi biologii i meditsiny | Bulletin of Experimental Biology and Medicine | Consultants Bureau | 41 | 1 | 1959 |
| DAN (SSSR) Dokl(ady) AN SSSR | Doklady Akademii Nauk SSSR | The translation of this journal is published in sections, as follows: | | | | |
| | Life Sciences | Doklady Biochemistry Section | American Institute of Biological Sciences | 106 | 1 | 1956 |
| | Life Sciences | Doklady Biological Sciences Sections (Includes: Anatomy, biophysics, cytology, ecology, embryology, endocrinology, evolutionary morphology, genetics, histology, hydrobiology microbiology, morphology, parasitology, physiology, zoology sections) | American Institute of Biological Sciences | 112 | 1 | 1957 |
| | Life Sciences | Doklady Botanical Sciences Sections (Includes: Botany, phytopathology, plant anatomy, plant ecology, plant embryology, plant physiology, plant morphology sections) | American Institute of Biological Sciences | 112 | 1 | 1957 |
| | Chemical Sciences | Proceedings of the Academy of Sciences of the USSR, Section: Chemical Technology | Consultants Bureau | 106 | 1 | 1956 |
| | Chemical Sciences | Proceedings of the Academy of Sciences of the USSR, Section: Chemistry | Consultants Bureau | 106 | 1 | 1956 |
| | Chemical Sciences | Proceedings of the Academy of Sciences of the USSR, Section: Physical Chemistry | Consultants Bureau | 112 | 1 | 1957 |
| | Earth Sciences | Doklady Earth Sciences Sections (Includes: Geochemistry, geology, geophysics, hydrogeology, mineralogy, paleontology, petrography, permafrost sections) | American Geological Institute | 124 | 1 | 1959 |
| | Earth Sciences | Proceedings of the Academy of Sciences of the USSR, Section: Geochemistry | Consultants Bureau | 106-123 | 1 6 | 1957-1958 |
| | Earth Sciences | Proceedings of the Academy of Sciences of the USSR, Sections: Geology | Consultants Bureau | 106-123 | 1 6 | 1957-1958 |
| | Mathematics | Doklady Soviet Mathematics | The American Mathematics Society | 131 | 1 | 1961 |
| | Physics | Soviet Physics–Doklady (Includes: Aerodynamics, astronomy, crystallography, cybernetics and control theory, electrical engineering, energetics, fluid mechanics, heat engineering, hydraulics, mathematical physics, mechanics, physics, technical physics, theory of elasticity sections) | American Institute of Physics | 106 | 1 | 1956 |
| | Physics | Proceedings of the Academy of Sciences of the USSR, Applied Physics Sections (does not include mathematical physics or physics sections) | Consultants Bureau | 106-117 | 1 | 1956-1957 |
| Derevoobrabat. prom-st'. | Derevoobrabatyvayushchaya promyshlennost' | Wood Processing Industry | Timber Development Association (London) | | 9 | 1959 |
| | Élecktrosvyaz | Telecommunications | Massachusetts Institute of Technology* | | 1 | 1957 |
| Éntom(ol). oboz(renie) | Éntomologicheskoe obozrenie | Entomological Review | American Institute of Biological Sciences | 38 | 1 | 1959 |
| Farmakol. (i) toksikol(ogiya) | Farmakologiya i toksikologiya | Pharmacology and Toxicology | Consultants Bureau | 20 | 1 | 1957 |
| FMM | Fizika metallov i metallovedenie | Physics of Metals and Metallography | Acta Metallurgica* | 5 | 1 | 1957 |
| Fiziol. zhurn. SSSR (im. Sechenova) | Fiziologicheskii zhurnal im. I. M. Sechenova | Sechenov Physiological Journal USSR | National Institutes of Health* | | 1 | 1957 |
| Fiziol(ogiya) rast. | Fiziologiya rastenii | Plant Physiology | American Institute of Biological Sciences | 4 | 1 | 1957 |
| | Geokhimiya | Geochemistry | The Geochemical Society | | 1 | 1958 |
| FTT | Fizika tverdogo tela | Soviet Physics–Solid State | American Institute of Physics | 1 | 1 | 1959 |
| Izmerit. tekh(nika) | Izmeritel'naya tekhnika | Measurement Techniques | Instrument Society of America | | 1 | 1959 |
| Izv. AN SSSR, O(td). Kh(im). N(auk) | Izvestiya Akademii Nauk SSSR: Otdelenie khimicheskikh nauk | Bulletin of the Academy of Sciences of the USSR: Division of Chemical Sciences | Consultants Bureau | | 1 | 1952 |

*continued*

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|---|---|---|---|---|---|---|
| Izv. AN SSSR, O(td). T(ekhn). N(auk): Met(all). i top. | (see Met. i top.) | | | | | |
| Izv. AN SSSR Ser. fiz(ich). | Izvestiya Akademii Nauk SSSR: Seriya fizicheskaya | Bulletin of the Academy of Sciences of the USSR: Physical Series | Columbia Technical Translations | | 1 | 1954 |
| Izv. AN SSSR Ser. geofiz. | Izvestiya Akademii Nauk SSSR: Seriya geofizicheskaya | Bulletin (Izvestiya) of the Academy of Sciences USSR: Geophysics Series | American Geophysical Union | | 1 | 1954 |
| Izv. AN SSSR Ser. geol. | Izvestiya Akademii Nauk SSSR: Seriya geologicheskaya | Izvestiya of the Academy of Sciences of the USSR: Geologic Series | American Geological Institute | | 1 | 1958 |
| Kauch. i rez. | Kauchuk i rezina | Soviet Rubber Technology | Research Association of British Rubber Manufacturers | 18 | 1 | 1959 |
| | Kinetika i kataliz | Kinetics and Catalysis | Consultants Bureau | 1 | 3 | 1960 |
| | Koks i khimiya | Coke and Chemistry USSR | Coal Tar Research Association (Leeds, England) | | 1 | 1958 |
| Kolloidn. zh(urn). | Kolloidnyi zhurnal | Colloid Journal | Consultants Bureau | 14 | 1 | 1952 |
| | Kristallografiya | Soviet Physics – Crystallography | American Institute of Physics | 2 | 1 | 1957 |
| Metalov. i term. obrabot. metal. | Metallovedenie i termicheskaya obrabotka metallov | Metal Science and Heat Treatment of Metals | Acta Metallurgica | 6 | 1 | 1958 |
| | Metallurg | Metallurgist | Acta Metallurgica | | 1 | 1957 |
| Met. i top. | Metallurgiya i topliva | Russian Metallurgy and Fuels | Eagle Technical Publications | | 1 | 1960 |
| Mikrobiol. | Mikrobiologiya | Microbiology | American Institute of Biological Sciences | 26 | 1 | 1957 |
| OS | Optika i spektroskopiya | Optics and Spectroscopy | American Institute of Physics | | 6 | 1959 |
| | Pochvovedenie | Soviet Soil Science | American Institute of Biological Sciences | | 1 | 1958 |
| | Priborostroenie | Instrument Construction | British Scientific Instrument Research Association | | 1 | 1959 |
| Pribory i tekhn. éks(perimenta) | Pribory i tekhnika éksperimenta | Instruments and Experimental Techniques | Instrument Society of America | | 1 | 1957 |
| Prikl. matem. i mekh. | Prikladnaya matematika i mekhanika | Applied Mathematics and Mechanics | American Society of Mechanical Engineers | | 1 | 1958 |
| PTÉ | (see Pribory i tekhn. éks.) | | | | | |
| | Problemy Severa | Problems of the North | National Research Council of Canada | | | |
| Radiotekh. | Radiotekhnika | Radio Engineering | Massachusetts Institute of Technology* | 12 | 1 | 1957 |
| Radiotekh. i élektronika | Radiotekhnika i élektronika | Radio Engineering and Electronics | Massachusetts Institute of Technology* | 2 | 1 | 1957 |
| | Stanki i instrument | Machines and Tooling | Production Engineering Research Assoc. | | 1 | 1959 |
| | Stal' | Stal (In English) | Iron and Steel Institute | | 1 | 1959 |
| Stek. i keram. | Steklo i keramika | Glass and Ceramics | Consultants Bureau | 13 | 1 | 1956 |
| Svaroch. proiz-vo | Svarochnoe proizvodstvo | Welding Production | British Welding Research Association | | 4 | 1959 |
| Teor. veroyat. i prim. | Teoriya veroyatnostei i ee primenenie | Theory of Probability and Its Applications | Society for Industrial and Applied Mathematics | | 1 | 1956 |
| Tsvet. Metally | Tsvetnye metally | Nonferrous Metals | Primary Sources | | 1 | 1960 |
| UFN | Uspekhi fizicheskikh Nauk | Soviet Physics – Uspekhi (partial translation) | American Institute of Physics | 66 | 1 | 1958 |
| UKh | Uspekhi khimii | Russian Chemical Reviews | The Chemical Society (London) | | 1 | 1960 |
| UMN | Uspekhi matematicheskikh nauk | Russian Mathematical Surveys | London Mathematical Society | 15 | 1 | 1960 |
| Usp. fiz. nauk | (see UFN) | | | | | |
| Usp. khim(ii) | (see UKh) | | | | | |
| Usp. matem. nauk | (see UMN) | | | | | |
| Usp. sovr. biol. | Uspekhi sovremennoi biologii | Russian Review of Biology | Oliver and Boyd | | 48 | 1959 |
| Vest. mashinostroeniya | Vestnik mashinostroeniya | Russian Engineering Journal | Production Engineering Research Assoc. | | 4 | 1959 |
| Vop. gem. i per. krovi | Voprosy gematologii i perelivaniya krovi | Problems of Hematology and Blood Transfusion | National Institutes of Health* | | 1 | 1957 |
| Vop. onk. | Voprosy onkologii | Problems of Oncology | National Institutes of Health* | | 1 | 1957 |
| Vop. virusol. | Voprosy virusologii | Problems of Virology | National Institutes of Health* | | 1 | 1957 |
| Zav(odsk). lab(oratoriya) | Zavodskaya laboratoriya | Industrial Laboratory | Instrument Society of America | 25 | 1 | 1959 |
| ZhAKh Zh. anal(it). khimii | Zhurnal analiticheskoi khimii | Journal of Analytical Chemistry USSR | Consultants Bureau | 7 | 1 | 1952 |
| ZhETF<br>Zh. éksperim. i teor. fiz. | Zhurnal éksperimental'noi i theoreticheskoi fiziki | Soviet Physics–JETP | American Institute of Physics | 28 | 1 | 1955 |
| ZhFKh Zh. fiz. khimii | Zhurnal fizicheskoi khimii | Russian Journal of Physical Chemistry | The Chemical Society (London) | | 7 | 1959 |
| ZhMÉI Zh(urn). mikrobiol. épidemiol. i immunobiol. | Zhurnal mikrobiologii, épidemiologii i immunobiologii | Journal of Microbiology, Epidemiology and Immunobiology | National Institutes of Health* | | 1 | 1957 |
| ZhNKh<br>Zh(urn). neorgan(ich). khim(ii) | Zhurnal neorganicheskoi khimii | The Russian Journal of Inorganic Chemistry | The Chemical Society (London) | | 1 | 1959 |
| ZhOKh<br>Zh(urn). obshch(ei) khimii | Zhurnal obshchei khimii | Journal of General Chemistry USSR | Consultants Bureau | 19 | 1 | 1949 |
| ZhPKh<br>Zh(urn). prikl. khimii | Zhurnal prikladnoi khimii | Journal of Applied Chemistry USSR | Consultants Bureau | 23 | 1 | 1950 |
| ZhSKh<br>Zh(urn). strukt. khimii | Zhurnal strukturnoi khimii | Journal of Structural Chemistry | Consultants Bureau | 1 | 1 | 1960 |
| ZhTF<br>Zh(urn). tekhn. fiz. | Zhurnal teknicheskoi fiziki | Soviet Physics–Technical Physics | American Institute of Physics | 26 | 1 | 1956 |
| Zh(urn). vyssh. nervn. deyat. (im. Pavlova) | Zhurnal vysshei nervnoi deyatel'nosti (im. I. P. Pavlova) | Pavlov Journal of Higher Nervous Activity | National Institutes of Health* | | 1 | 1958 |

*Sponsoring organization. Translation through 1960 issues is a publication of Pergamon Press.

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| deyat. (im. Pavlova) | deyatel'nosti (im. I. P. Pavlova) | Pavlov Journal of Higher Nervous Activity | National Institutes of Health* | 1 | 1958 |

*Sponsoring organization. Translation through 1960 issues is a publication of Pergamon Press.

## SIGNIFICANCE OF ABBREVIATIONS MOST FREQUENTLY ENCOUNTERED IN SOVIET TECHNICAL PERIODICALS

| | |
|---|---|
| **AN SSSR** | *Academy of Sciences, USSR* |
| **FIAN** | *Physics Institute, Academy of Sciences USSR* |
| **GITI** | *State Scientific and Technical Press* |
| **GITTL** | *State Press for Technical and Theoretical Literature* |
| **GOI** | *State Optical Institute* |
| **GONTI** | *State United Scientific and Technical Press* |
| **Gosénergoizdat** | *State Power Press* |
| **Gosfizkhimizdat** | *State Physical Chemistry Press* |
| **Goskhimizdat** | *State Chemistry Press* |
| **GOST** | *All-Union State Standard* |
| **Gostekhizdat** | *State Technical Press* |
| **GTTI** | *State Technical and Theoretical Press* |
| **IAT** | *Institute of Automation and Remote Control* |
| **IF KhI** | *Institute of Physical Chemistry Research* |
| **IFP** | *Institute of Physical Problems* |
| **IL** | *Foreign Literature Press* |
| **IPF** | *Institute of Applied Physics* |
| **IPM** | *Institute of Applied Mathematics* |
| **IREA** | *Institute of Chemical Reagents* |
| **ISN (Izd. Sov. Nauk)** | *Soviet Science Press* |
| **IYap** | *Institute of Nuclear Studies* |
| **Izd** | *Press (publishing house)* |
| **LÉTI** | *Leningrad Electrotechnical Institute* |
| **LFTI** | *Leningrad Institute of Physics and Technology* |
| **LIM** | *Leningrad Institute of Metals* |
| **LITMiO** | *Leningrad Institute of Precision Instruments and Optics* |
| **Mashgiz** | *State Scientific-Technical Press for Machine Construction Literature* |
| **MGU** | *Moscow State University* |
| **Metallurgizdat** | *Metallurgy Press* |
| **MOPI** | *Moscow Regional Pedagogical Institute* |
| **NIAFIZ** | *Scientific Research Association for Physics* |
| **NIFI** | *Scientific Research Institute of Physics* |
| **NIIMM** | *Scientific Research Institute of Mathematics and Mechanics* |
| **NIKFI** | *Scientific Institute of Motion Picture Photography* |
| **NKTM** | *People's Commissariat of the Heavy Machinery Industry* |
| **Obrongiz** | *State Press of the Defense Industry* |
| **OIYaI** | *Joint Institute of Nuclear Studies* |
| **ONTI** | *United Scientific and Technical Press* |
| **OTI** | *Division of Technical Information* |
| **OTN** | *Division of Technical Science* |
| **RIAN** | *Radium Institute, Academy of Sciences of the USSR* |
| **SPB** | *All-Union Special Planning Office* |
| **Stroiizdat** | *Construction Press* |
| **URALFTI** | *Ural Institute of Physics and Technology* |
| **TsNIITMASh** | *Central Scientific-Research Institute of Technology and Machinery* |
| **VNIIM** | *All-Union Scientific Research Institute of Metrology* |

NOTE: Abbreviations not on this list and not explained in the translation have been transliterated, no further information about their significance being available to us — *Publisher.*

Publication of a "Soviet Instrumentation and Control Translation Series" by the Instrument Society of America has been made possible by a grant in aid from the National Science Foundation, with additional assistance from the National Bureau of Standards for the journal *Measurement Techniques.*

Subscription rates have been set at modest levels to permit widest possible distribution of these translated journals.

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*Russian original published by the Committee of Standards, Measures, and Measuring Instruments of the Council of Ministers, USSR. The articles in this journal are of interest to all who are engaged in the study and application of fundamental measurements. Both 1958 (bimonthly) and 1959-1961 (monthlies) available.*

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| Libraries of nonprofit academic institutions: | | |
| | United States and Canada | $12.50 |
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## INSTRUMENTS AND EXPERIMENTAL TECHNIQUES
*Pribory i Tekhnika Éksperimenta*

*Russian original published by the Academy of Sciences, USSR. The articles in this journal relate to the function, construction, application, and operation of instruments in various fields of experimentation. 1958-1961 issues available.*

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| | Elsewhere | 15.50 |

## AUTOMATION AND REMOTE CONTROL – *Avtomatika i Telemekhanika*

*Russian original published by the Institute of Automation and Remote Control of the Academy of Sciences, USSR. The articles are concerned with analysis of all phases of automatic control theory and techniques. 1957-1961 1959, and 1960*

Per year (12 issues) starting with Vol. 22, No. 1

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| | United States and Canada | $17.50 |
| | Elsewhere | 20.50 |

## INDUSTRIAL LABORATORY – *Zavodskaya Laboratoriya*

*Russian original published by the Ministry of Light Metals, USSR. The articles in this journal relate to instrumentation for analytical chemistry and to physical and mechanical methods of materials research and testing. 1958-1961 issues available.*

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